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EUGENE K. RADER AND THOMAS H. BIGGS

REPORT OF INVESTIGATIONS 40

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COMMONWEALTH OF VIRGINIA
DEPARTMENT OF CONSERVATION
AND ECONOMIC DEVELOPMENT
DIVISION OF MINERAL RESOURCES

GEOLOGY OF THE FRONT ROYAL QUADRANGLE, VIRGINIA

By EUGENE K. RADER AND THOMAS H. BIGGS

With a section on HYDROGEOLOGY
By RICHARD H. DEKAY

REPORT OF INVESTIGATIONS 40

VIRGINIA DIVISION OF MINERAL RESOURCES
James L. Calver
Commissioner of Mineral Resources and State Geologist

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GEOLOGY OF THE FRONT ROYAL QUADRANGLE, VIRGINIA

By

Eugene K. Rader and Thomas H. Biggs

ABSTRACT

The Front Royal 7.5-minute quadrangle is located in Warren County, northern Virginia. The area is mostly in the Valley and Ridge physiographic province but approximately 20 percent is in the Blue Ridge province. The bedrock ranges in age from Precambrian (Pedlar Formation) through Middle Ordovician (Martinsburg Formation). The Precambrian and Paleozoic rocks are assigned to 15 formations and 20 mappable units. Additionally, Cenozoic sediments consisting of terrace deposits, colluvium, and alluvium are mapped.

The major structural features consist of the southeastern limb of the Massanutten synclinorium and an overthrust salient of the Blue Ridge anticlinorium. The present attitude of the bedrock is the result of at least two tectonic events from the east which produced oversteepened and locally overturned east limbs of synclines and west limbs of anticlines. The major faults have an easterly dip, with both high- and low-angle faults present. The major fold axes of the area trend to the northeast along the general strike of the formational outcrops. Well-developed cleavage, commonly exhibiting two generations of deformation, and joints are exposed at many localities.

Impure limestone and crushed and broken stone are produced. Iron, manganese, and copper ores have been mined in the past. Limestone, dolomite, sandstone, and shale are available as raw materials for many purposes. The five clastic sedimentary formations are consistent producers of small to moderate yields of water from intermediate depths, the eight carbonate formations have a wide range of water-well depths and yields, and the two igneous formations commonly yield only small quantities of water at relatively shallow depths.

Data for land-use decisions is provided by environmental geology information obtained from geological characteristics such as lithology, slope stability, erodibility, rockfall areas, sinkholes, and cave areas. Reference to soils and land-use potential is made.

INTRODUCTION

The Front Royal 7.5-minute quadrangle (Plate 1) is located in central Warren County, Virginia and has an area of about 58 square miles (150 sq km) (Figure 1). It is bounded by 78°07'30" and 78°15' west longitudes and 38°52'30" and 39°00' north latitudes. The quadrangle is mostly in the Valley and Ridge physiographic province, but approximately 20 percent is in the Blue Ridge province. Four distinctive topographic areas, two in each province, are present. In the southeastern portion of the quadrangle (Figure 2, Area 1) the topography consists of mountainous terrain with V-shaped valleys and steep-sided, linear, arcuate, and flat-topped ridges. A steep, northward-trending escarpment, forming the west slope of Dickey Ridge (Figure 3), parallel to the western boundary of the Shenandoah National Park separates areas 1 and 2 (Figure 2). Area 2 is triangular-shaped with high, steep-sided, linear hills extending westward from the escarpment along Dickey Ridge almost to U. S. Highway 340. Area 3 extends from the southwest corner of the map to the northeast corner. The Blue Ridge province bounds area 3 on the east, and Crooked Run and the South Fork of the Shenandoah River form the western boundary. The region is characterized by gently rolling linear to arcuate hills and broad valleys. West of Crooked Run the topography of area 4 consists of V-shaped valleys, a few broad U-shaped valleys, and deeply dissected linear and arcuate hills.

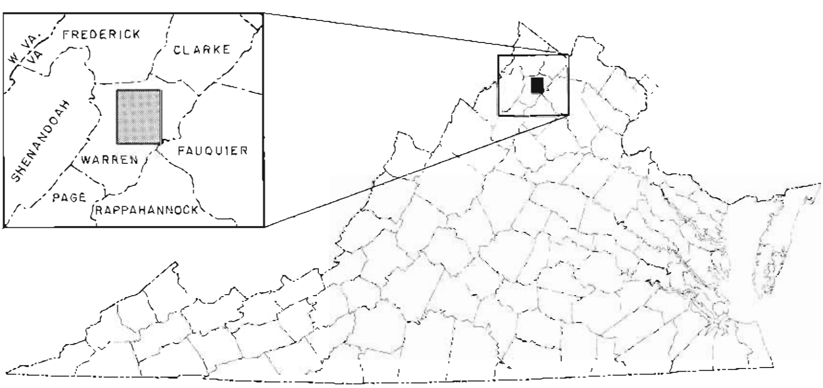

Figure 1. Index map showing location of the Front Royal quadrangle, Virginia.

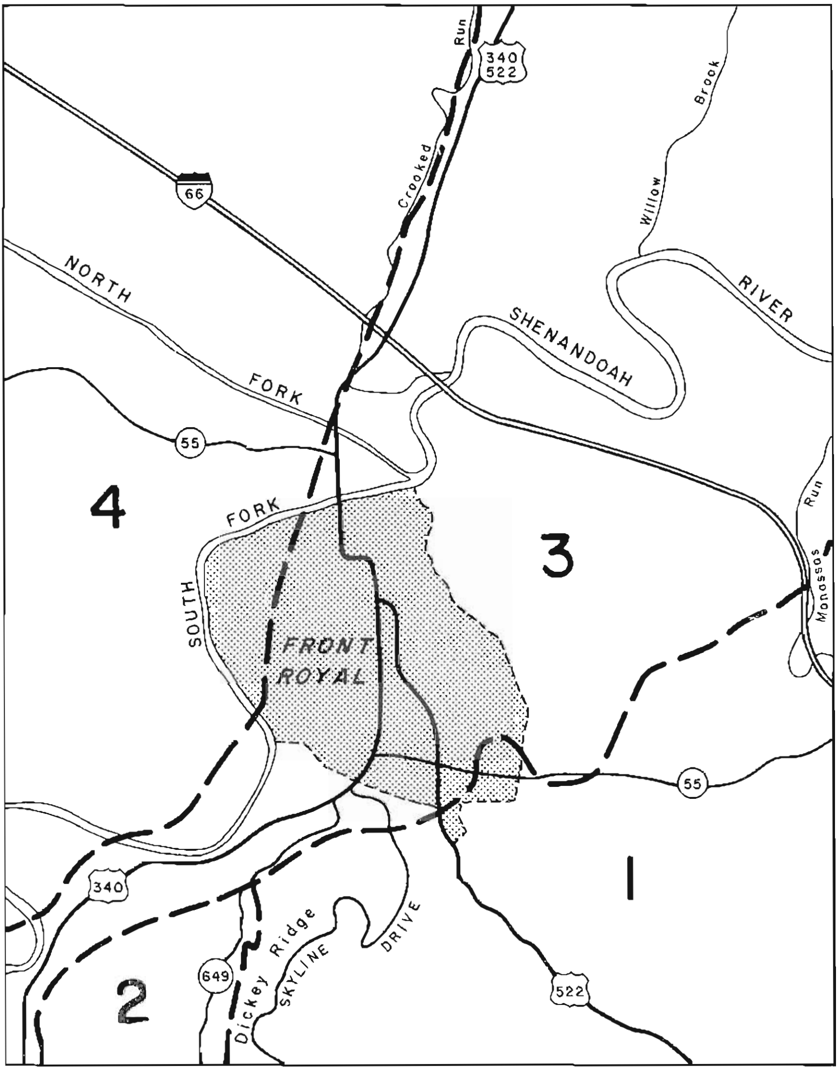

Figure 2. Topographic areas in the Front Royal quadrangle.

Elevations range from less than 440 feet (134 m) on the Shenandoah River east of Shenandoah Shores to more than 1,940 feet (591 m) on top of Dickey Ridge near the southern border of the quadrangle.

Access to the area is by Interstate Highway 66, U. S. Highways 340 and 522, State Highway 55, Skyline Drive, and several

Figure 3. Escarpment forming the west slope of Dickey Ridge; looking east from junction of State Roads 615 and 619.

State Roads. Railroad service is provided by the Norfolk and Western Railway and the Southern Railway.

The "Geologic Map of the Appalachian Valley of Virginia with Explanatory Text" (Butts, 1933), the "Geology of the Appalachian Valley in Virginia" (Butts, 1940-41) and the "Geologic Map of Virginia" (Virginia Division of Mineral Resources, 1963) provided useful regional data. Reports by Edmundson (1945), Wickham (1972), and Edmundson and Nunan (1973) and a thesis by Lee (1961) were utilized. An orthophotoquad became available in the spring of 1974 and was very useful. The field investigation was begun by W. E. Nunan in October 1970 and continued by him until July 1971. The writers continued the project from May 1973 until its completion in May 1974.

The writers wish to acknowledge the mapping by Nunan of the Pedlar, Catoctin, and Chilhowee rocks and to especially thank him for time spent with them in the field examining the Cambrian and Ordovician carbonate rocks. Discussions with T. M. Gathright, E. B. Nuckols, and R. S. Edmundson contributed to a better understanding of the stratigraphy and structure of the area. Discussions with Emil Onuschak, Jr., contributed to a

clearer understanding of the environmental geology. R. J. Maupin and R. L. Googins, U. S. Soil Conservation Service, furnished soils information that was incorporated into the section on Environmental Geology.

Numbers preceded by "R" in parentheses (R-649) correspond to sample localities; those preceded by "F" (F-889) correspond to fossil localities (Plate 1). These samples and fossils are on file in the repository of the Virginia Division of Mineral Resources where they are available for examination.

STRATIGRAPHY

The rock strata cropping out in the area are divided into 15 formations and 20 mappable units on the bases of lithologic character and fossils. The oldest rock exposed is the Pedlar Formation of Precambrian age and the youngest is the Martinsburg Formation of Ordovician age (Table 1). The area south of State Highway 55 is underlain by Precambrian (?) meta-igneous and metasedimentary rock. Green Hill is underlain by folded and faulted Lower Cambrian sandstone and shale. Between Green Hill and Crooked Run the area is underlain by folded and faulted Cambrian and Ordovician limestone, dolomite, and shale. West of Crooked Run the Ordovician lithic sandstone and shale are intensely folded.

Surficial sediments of Cenozoic age are of three broad types: terrace deposits, colluvium, and alluvium. Within the three broad categories there are five mapping units. Also, two types of breccia were mapped.

PRECAMBRIAN ROCKS

Pedlar Formation

The Pedlar Formation occurs in a triangular area between Dickey Ridge and U. S. Highway 340. There are good exposures in the streams east of Dungadin Heights and scattered outcrops along State Road 607. The Pedlar forms the foothills west of the escarpment forming the west slope of Dickey Ridge. The formation is in fault contact with the younger Rockdale Run Formation. Its upper contact with the Catoctin is sharp and somewhat irregular and is commonly marked by a zone of unakite and a sharp break in slope. A good exposure occurs 0.3 mile (0.5 km) southeast of the entrance to Skyline Caverns on State Road 649.

Table 1.—Geologic formations in the Front Royal quadrangle.

Age	Name	Character	Thickness in feet (meters)
Quaternary	Alluvium	Dark-brown clayey sand and silt; mollusk shells along Shenandoah River; roundstones locally common.	10-15± (3-5±)
Quaternary	Colluvium	Angular cobbles and boulders in sand and clay matrix.	0-25± (0-8±)
Quaternary	Terrace deposits	*Low-level deposits:* pebbles and cobbles of sandstone and quartzite in a matrix of sandy clay. *Middle-level deposits:* pebbles and cobbles of sandstone and quartzite in a matrix of sand, clay and silt; locally, ironstone breccia. *High-level deposits:* pebbles, cobbles and boulders of sandstone, quartzite, and conglomerate in a matrix of clay, silt, and quartz sand.	0-25± (0-8±)
Ordovician	Martinsburg Formation	Alternating thin, olive-green to gray shale and greenish-gray lithic sandstone; basal part is black, silty shale and scattered, thin beds of black limestone.	3,000— (914—)
Ordovician	Oranda Formation	Coarse-grained, decalcified siltstone; fossiliferous.	15 (5)
Ordovician	Edinburg Formation	Black, fissile shale; dark-gray, micrograined limestone; thin beds of medium-grained, cobbly-weathering limestone; fossiliferous.	435± (133±)
Ordovician	Lincolnshire Formation	Gray, medium-grained limestone; locally, black and dark-gray, blocky chert; thin beds of light-gray coarse-grained bioclastic limestone; fossiliferous.	25-50 (8-15)
Ordovician	New Market Limestone	Bluish- to dove-gray, micritic limestone (upper part). Carbonate-pebble, -cobble, and -boulder conglomerate (lower part).	0-60± (0-18±)
Ordovician	Beekmantown Group: Rockdale Run Formation	Mostly gray, fine-grained limestone; dolomitic limestone, dolomite, and thin lenses of sandstone and chert are present; fossils locally abundant.	2,400 (732)
Ordovician	Beekmantown Group: Stonehenge Formation	Gray to black limestone; siliceous laminae and algal structures near top; fossils locally abundant.	600-650 (183-198)

Age	Name	Character	Thickness in feet (meters)
Cambrian	Conococheague Formation	Gray, laminated dolomite and lesser amount of limestone and conglomerate (upper part). Ribbon-banded limestone and dolomite, limestone with siliceous laminae, some dolomite and conglomerate (middle part). *Big Spring Station member*: calcareous sandstone, laminated limestone, dolomitic limestone, dolomite, and intraformational conglomerate (lower part).	2,300 (701)
	Elbrook Formation	Yellow - weathering, light - gray, laminated dolomite and blue, algal limestone (upper part). Gray limestone, dolomitic limestone, dolomite, and dolomitic shale (middle part). Green to greenish-gray dolomite, dolomitic limestone, shale, and rusty brown weathering siltstone (lower part).	2,000 ± (610 ±)
	Waynesboro (Rome) Formation	Maroon and green shale with maroon to rusty brown sandstone (upper part). Saccharoidal dolomite, bluish - gray limestone, coarse-grained dolomite, and medium- to fine-grained dolomite (middle part). Maroon, olive, and dark-gray shale, maroon to pale-orange sandstone, and gray limestone (lower part).	800 ± (244 ±)
	Antietam Formation	White, rusty weathering quartzite; subarkosic quartzite; and quartz-granule and -pebble conglomerate.	400 (122)
	Harpers Formation	*Upper member*: gray, sandy phyllite, quartzite, subarkosic quartzite, meta-arkose, and feldspathic phyllite. *Lower member*: gray, sandy and silty, feldspathic phyllite and metalithic sandstone; gray, red, tan, and pink phyllite which weathers to bronze-colored chips.	2,000 (610)
	Weverton Formation	*Quartz-pebble conglomerate member*: Ferruginous granule to pebble quartz conglomerate. *Silty phyllite member*: Olive-gray, silty phyllite,	

Age	Name	Character	Thickness in feet (meters)
Cambrian	Weverton Formation	phyllitic sandstone, and quartz sandstone. *Subarkose member*: Gray subarkose. *Laminated phyllite member*: Olive-gray phyllite and conglomeratic phyllite. *Basal conglomerate member*: Clayey, sandy, pebble conglomerate.	400-500 (122-152)
Precambrian (?)	Catoctin Formation	Greenstone, flow breccia, epidosite, green phyllite, red argillite, meta-arkose, metalithic sandstone.	1,500-2,500 (457-762)
Precambrian	Pedlar Formation	Hypersthene granodiorite and quartzofeldspathic granulite intruded by greenstone dikes.	

The Pedlar is an assemblage of meta-igneous rocks consisting of quartzofeldspathic granulite (R-4372, R-4373) and altered hypersthene granodiorite. The granulite includes quartz, perthite, epidote, garnet, rutile, zeolite, ilmenite, and leucoxene. The greenish-gray granodiorite contains quartz, microcline, plagioclase, pyroxene altered to tremolite and chlorite, biotite, muscovite, specular hematite, pyrite, and chalcopyrite. South of Dungadin Heights the Pedlar is intruded by fine-grained greenstone dikes (R-4371) (Figure 4). Radiometric age determinations from zircons in granodiorite near Marys Rock tunnel (about 16 miles south-southwest of the Front Royal quadrangle) provide a date of 1,100 million years (Davis, and others, 1958).

PRECAMBRIAN (?) ROCKS

Catoctin Formation

East of the escarpment along the west slope of Dickey Ridge and south of State Highway 55 the area is underlain by metabasalt and associated metavolcanic and metasedimentary rocks of the Catoctin Formation. The Catoctin contact with the Pedlar is nonconformable. Along State Road 649, 0.3 mile (0.5 km)

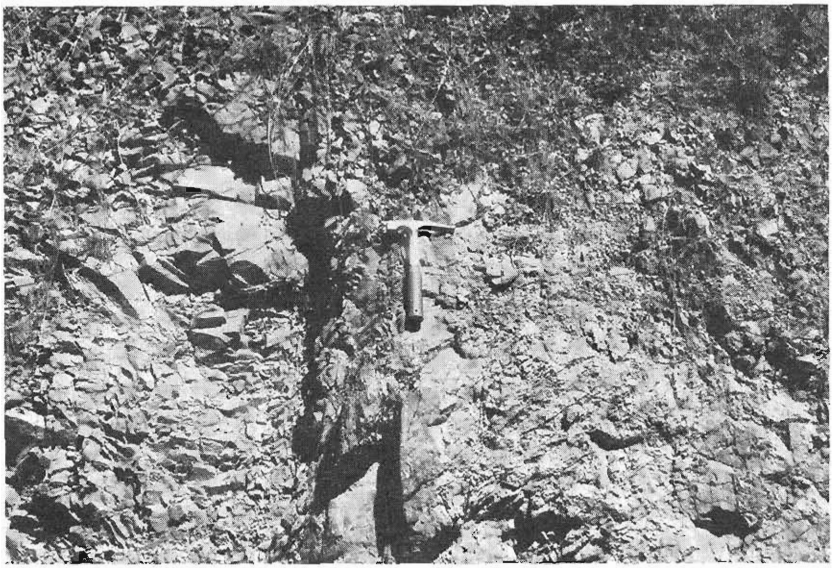

Figure 4. Contact of granodiorite (right of hammer) and greenstone dike (left of hammer) of the Pedlar Formation north of State Road 607, 0.25 mile (0.40 km) east of junction of U. S. Highway 340 and State Road 607.

southeast of Skyline Caverns the Lower Catoctin contact is exposed. Here unakite of the Pedlar is in contact with grayish-green metabasalt. Due south about 0.5 mile (0.8 km) the unakite is overlain by a thin purple arkose and metarhyolite. The upper contact of the Catoctin with the Weverton is unconformable. Along the small hill 1,700 feet west of where State Highway 55 crosses 78°07'30"W., purple slates and metabasalts of the Catoctin are overlain by a basal Weverton conglomerate. East and west of the hill the Catoctin is overlain by younger sandstones and phyllites of the Weverton.

The most common rock type in the Catoctin is greenstone. The greenstone is the product of low-grade regional metamorphism of a basalt flow. The mineral composition of the greenstone is albite (lath-shaped), epidote, chlorite, actinolite, and minor quartz, magnetite, specular hematite, sphene and pyroxene (R-5604, R-5699). Amygdule fillings consist of white albite, quartz, calcite, green epidote, chlorite, and red jasper. Porphyritic greenstone with plagioclase phenocrysts in a matrix of fine-grained albite, epidote, magnetite, and pyroxene is exposed about 1.0 mile (1.6 km) south of Front Royal along U. S. Highway 522.

Commonly, the top of a flow is marked by a zone of breccia consisting of amygdaloidal greenstone, phyllite, and red argillite (R-5603). "The epidote-amygdaloid breccia is composed of angular or irregularly rounded fragments of purple, red, and bluish-gray amygdaloidal greenstone set in a matrix of fine-grained greenstone, quartz, and epidote" (Reed, 1969). Epidosite is very common in breccia zones (R-4369, R-4370, R-5600, R-5601, R-5605). Mud-lump breccias consisting of angular to subangular fragments of reddish-brown argillite in a matrix of fine-grained schistose greenstone occur locally at the base of flows. Columnar jointing is common in the flows and the columns are often replaced by epidote and quartz. Purple rhyolitic tuffs (R-5602, R-5607) with a phyllitic texture and green-smeared epidote blebs are common at or near the top of the Catoctin.

Metasedimentary rocks interbedded with the Catoctin flows are of three types: meta-arkose, metalithic sandstone (R-5608), and phyllite. The meta-arkose is composed of angular to subrounded quartz and feldspar in a matrix of sericite and epidote. A conglomeratic texture is locally common with granules and pebbles of quartz, gneiss, phyllite, and greenstone. The metalithic sandstone is composed of poorly sorted quartz, feldspar, and rock fragments of gneiss, phyllite, and greenstone in a matrix of chlorite and sericite. The matrix constitutes 20 to 50 percent of the rock. Granules and pebbles of quartz, gneiss, phyllite, and greenstone locally give the rock a conglomeratic texture. The phyllites are composed of sericite with scattered quartz grains and may be altered volcanic ash layers.

The thickness of the Catoctin is difficult to determine because the upper and lower contacts are not exposed on the same fault block. Estimates of 1,500 to 2,500 feet (457 to 762 m) based on the outcrop width and the general structural configuration are compatible with thicknesses reported to the north by Gathright and Nystrom (1974). A late Precambrian age of 820 million years has been reported for the lower Catoctin of Pennsylvania (Rankin and others, 1969).

CAMBRIAN SYSTEM

Weverton Formation

The Weverton Formation is a sequence of coarse-grained sandstones and pelitic rocks, which has been subdivided into five separately mapped members. The basal contact of the Weverton may be angular to the underlying Catoctin; the upper contact with the Harpers is conformable and gradational. Samples of the Weverton were collected along the Southern Railway in the Linden quadrangle adjacent to the east (R-4198 to R-4203, R-4208 to R-4212, R-4214, R-4218, R-4220).

Basal conglomerate member: The basal conglomerate member is present locally at the base of the Weverton as pod-shaped deposits, such as one on the crest of the ridge just north of State Highway 55 (Plate 1), 1,400 feet (427 m) west of the east border of the quadrangle where its contact with underlying purple metarhyolite(?) of the Catoctin Formation is exposed. The upper contact of the basal conglomerate member is placed at the base of the lowest phyllite bed of the overlying member. The clayey, sandy, pebble conglomerate is composed of pebbles of subrounded to well-rounded quartz (up to 35 mm in diameter) and flat clay clasts that have maximum dimensions as much as 85 x 10 mm. Some of the clay clasts may be weathered greenstone derived from the underlying Catoctin. The gravels are enclosed in a matrix of quartz-feldspar sand and clay. Complete exposures of the unit are not available; however, it is estimated to be approximately 30 feet (9 m) thick.

Laminated phyllite member: The laminated phyllite and conglomeratic phyllite extends northeast from where State Highway 55 crosses Leach Run to the east border of the quadrangle. The lower contact of the member is placed at the top of the basal conglomerate member, or in its absence at the top of the purple basalt of the Catoctin Formation. The upper contact is placed at the base of the overlying subarkose member. The member consists of olive-gray to dark greenish-gray, laminated phyllite with conglomeratic phyllite composed of subangular to subrounded quartz pebbles with average maximum diameters of 20 mm imbedded in a chlorite-sericite matrix. The thickness of the laminated phyllite member is about 200 feet (61 m) in exposures along a stream bluff north of where State Highway 55 crosses the Valley of Retreat.

Subarkose member: The subarkose member occurs in an 80- to 100-foot (24- to 30-m) -wide belt extending from Leach Run on the north side of State Highway 55 to the east border of the quadrangle. The base is the first subarkose above the laminated phyllite member and the top is below the first silty phyllite of the overlying member. The subarkose member is an olive-gray, cross-bedded subarkose composed of coarse-grained quartz and pink feldspar with a few grains up to 20 mm in diameter imbedded in a sericite matrix and minor silica cement. The sericite has partially replaced much of the original silica cement and most of the feldspar grains. The thickness is estimated to be 80 feet (24 m).

Silty phyllite member: The silty phyllite member occurs along the ridges southeast of Green Hill. It forms a low saddle between the subarkose member and the quartz-pebble conglomerate member which support the Weverton ridges. Its lower contact is at the top of the youngest underlying subarkose bed. The upper contact is at the base of the oldest bed in the quartz-pebble conglomerate member. Good exposures of this member are not present in the Front Royal quadrangle, but it can be examined in the railroad cuts along the Southern Railway tracks in the adjoining Linden quadrangle, about 0.4 mile (0.6 km) east of the eastern border of the Front Royal quadrangle. The member consists of olive- to greenish-gray, silty phyllite and lithic sandstone. Thin beds of limonite-stained quartz sandstone occur near the middle of the unit. The member is approximately 100 feet (30 m) thick.

Quartz-pebble conglomerate member: The quartz-pebble conglomerate member occurs in a narrow belt that parallels the older Weverton members. It extends from a small hill west of Leach Run and north of State Highway 55 northeastward to the east boundary of the quadrangle about 500 feet (152 m) south of the Southern Railway. This belt extends westward intermittently from that hill to a point on the south side of State Highway 55 about 1.0 mile (1.6 km) east of the junction of State Highway 55 and Jamestown Road. The member forms a low rise on the northwest side of the ridge crests that are supported by the upper three members of the Weverton. It forms steep cliffs where the beds are steep. The lower contact with the silty phyllite member is taken at the base of the oldest quartz conglomerate bed above the phyllite. The upper contact is placed at the top of the youngest quartz conglomerate bed. The conglomerate is ferruginous, and is overlain by beds which grade upward from the Weverton conglomerate into ferruginous phyllite in a thickness of about 10 feet (3 m). Exposures are present on the ridges south of Green Hill and northeast of the Valley of Retreat.

The quartz-pebble conglomerate member consists of light gray to rusty brown weathering, granule to pebble, blue and red quartz which is cemented by silica. The silica has been partially replaced by sericite and limonite. Feldspar grains and rock fragments are rare. The rocks are thick bedded and cross-bedded with lens-shaped ferruginous bodies defining the cross-bedding. This member ranges in thickness from 25 feet (8 m) near the eastern border of the quadrangle to about 75 feet (24 m) on the hills south of Green Hill.

Harpers Formation

The Harpers Formation, divided into two members, is comprised predominantly of pelitic phyllite and silty to sandy, fine-grained phyllite. In the upper member quartzite, sandstone, and meta-arkose are present and two quartzite beds have been separately mapped. Contacts with the underlying Weverton and the overlying Antietam are conformable and gradational. The total thickness of the Harpers is approximately 2,000 feet (610 m) in the Front Royal quadrangle. The formation occurs intermittently in a belt extending northeastward from the junction of Jamestown Road with State Highway 55 to the eastern border of the quadrangle.

Lower member: The lower member of the Harpers occurs in a 400-foot (122 m) -wide belt extending from the hill south of the junction of Jamestown Road and State Highway 55 to the east border of the quadrangle. To the southeast of Green Hill it underlies the deep draws between the ridges supported by underlying Weverton to the southeast and the overlying upper member of the Harpers to the northwest. The lower contact is placed at the top of the youngest quartz conglomerate bed in the Weverton. The upper contact is placed at the base of a ferruginous sandstone bed in the lower part of the upper member. The lower member is about 900 feet (274 m) thick. Exposures of the lower member can be examined in a southeastward-trending draw on the southwest slope of Green Hill and in roadcuts on the west side of Leach Run just north of where it flows under State Highway 55.

The lithologies in the lower member are of two basic types. The lower 200 to 300 feet (61 to 91 m) are predominantly light bluish-gray, brick-red, tan, and pink phyllite that weathers to bronze-colored chips. The basal 40 feet (12 m) have thin, purple, sandy phyllite interbedded with phyllite and metalithic sandstone. The upper 600 to 700 feet (183 to 213 m) of the lower member consist of olive-gray, sandy and silty, at places feldspathic, phyllite and metalithic sandstone (R-4206). Many grains have been partially replaced by the matrix which consists of fine-grained sericite and chlorite.

Upper member: The upper member of the Harpers is exposed in a belt that varies in width, because of structural complications, from 200 feet (61 m) on the hills south of Leach Run near Green Hill to about 1,600 feet (488 m) near the Southern Railway at the east border of the quadrangle. Sandstone beds in the upper member underlie linear ridges on the southeast side of Green Hill; two quartzite units, each about 100 feet (30 m) thick, have been mapped in the lower part (Figure 5). The lower contact is placed at the base of a ferruginous metasandstone overlying phyllite in the lower member. The upper contact is at the base of the ridge-forming, vitreous, *Skolithos*-bearing quartzite of the Antietam Formation. The upper member is about 1,100 feet (335 m) thick on the southeast flank of Green Hill. Exposures of the

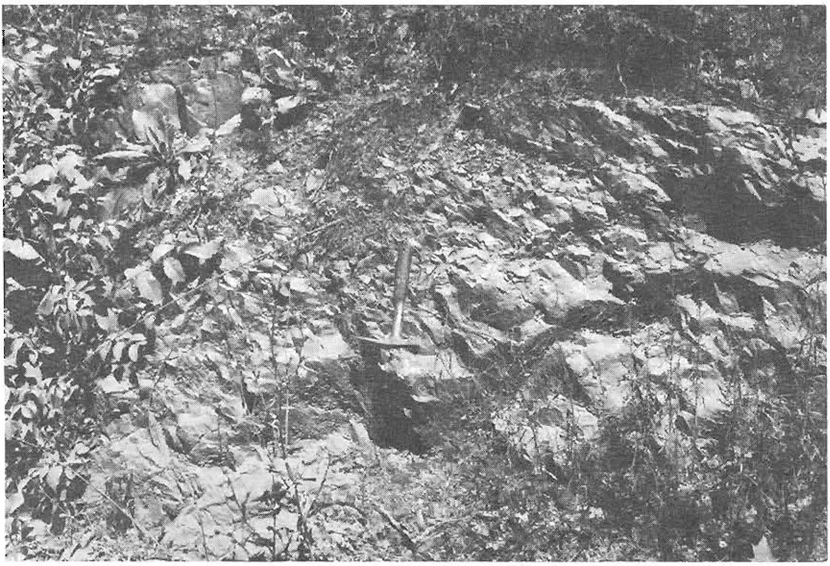

Figure 5. Quartzite unit in the upper member of the Harpers Formation along State Road 624 in Dismal Hollow, 0.85 mile (1.37 km) south of Bench Mark 541.

upper member are present along State Road 647 in Dismal Hollow and along the Southern Railway about 0.8 mile (1.3 km) southeast of the community of Happy Creek.

Rocks in the upper member include bluish-gray, sandy phyllite, light-gray quartzite (R-4217), subarkosic quartzite (R-4216), conglomeratic quartz sandstone (R-4215), meta-arkose, and feldspathic phyllite. The arenaceous beds comprise about 20 percent of the total thickness of the upper member. The basal ferruginous quartzite is locally conglomeratic.

Antietam Formation

The Antietam Formation is located in a sinous belt extending along the ridge of Green Hill, about 0.6 mile (1.0 km) south of the community of Happy Creek. It is also present in fault slices north of Dungadin Heights and between Woodland Park and State Highway 55. The lower contact of the Antietam is placed at the base of a ridge-forming, vitreous, *Skolithos*-bearing quartzite overlying sandy phyllite in the upper member of the Harpers Formation. Because Antietam rocks have been thrust over the Waynesboro Formation in the Front Royal quadrangle, the stratigraphy of the upper part of the Antietam and its stratigraphic relationship to younger rocks in the quadrangle is unknown. The upper part of the Antietam Formation, the entire Shady Formation, and the lower part of the Waynesboro Formation are missing because of faulting. The basal quartzite in the Antietam is about 400 feet (122 m) thick in exposures along the Southern Railway at the north end of Green Hill. It is also exposed along the crest of Green Hill. The Antietam is comprised of quartzite (R-4205), subarkosic quartzite, and quartz-granule and -pebble conglomerate. The quartzite contains only a fraction of 1 percent of clay, mica, and iron. *Skolithos* tubes are present in several beds.

The fault breccia (Plate 1) between the Antietam and Waynesboro formations is mapped as a separate unit. Exposures and float of breccia occur from the abandoned iron mines (Plate 1, numbers 10 and 11) at the southwest end of Green Hill and along the northwest slope to Manassas Run. The best exposures are between the Southern Railway and Interstate Highway 66 at the north end of Green Hill and in the abandoned iron mines (Figure 6). The angular quartzite fragments range from 0.25 inch to 3

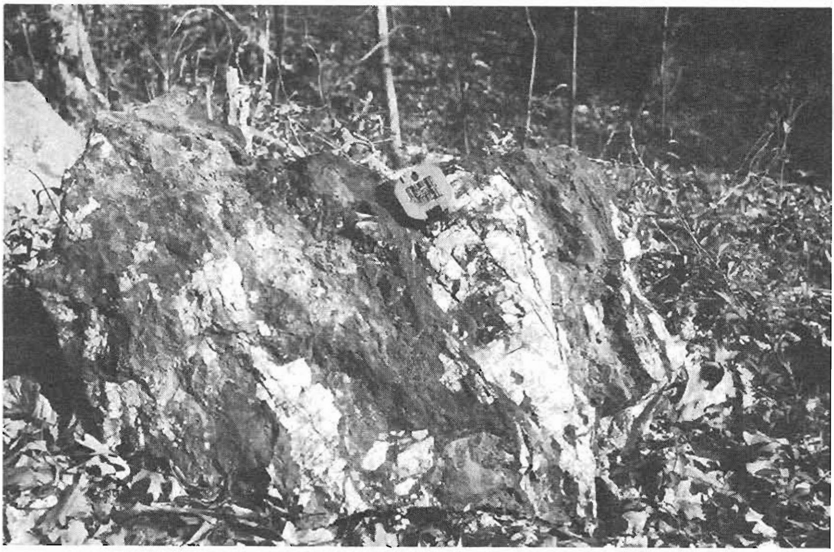

Figure 6. Fault breccia along the Happy Creek fault near the iron mine (Plate 1, abandoned mine number 11) at the southwest end of Green Hill.

feet (0.64 to 91 cm) in longest dimension. Goethite and hematite (iron oxides) comprise the bulk of the cement (R-4225, R-4381, R-5614).

Waynesboro (Rome) Formation

Edmundson and Nunan (1973) and Gathright and Nystrom (1974) mapped the Rome Formation consisting of four lithologic units northeast of the Front Royal quadrangle in Clarke County. Based on the descriptions of the Elbrook and Waynesboro formations at their type areas in southern Pennsylvania (Stose, 1906, 1909; Root, 1968) the upper 1,200 feet (366 m) of the Rome as mapped in Clarke County is correlative with the lower Elbrook. At Waynesboro, Pennsylvania, 75 miles (120 km) to the north of Front Royal, the rocks between the Tomstown (Shady) and Elbrook have been divided into three lithologic units: lower clastic-carbonate, middle carbonate, and upper clastic. Each of these three units have been recognized in the Ashby Gap quadrangle (Gathright and Nystrom, 1974) and in the Front Royal quadrangle. Because the lithologies in the Front Royal area are similar to those at the Waynesboro type locality in Pennsylvania and differ so greatly from the Rome type locality in Georgia, the name Waynesboro is used in this report.

The Waynesboro Formation occupies a sinuous belt about 3,000 feet (914 m) wide extending northeastward from just south of State Highway 55 and about 2,000 feet (610 m) east of Jamestown Road to a point a few hundred feet south of the Shenandoah River at the eastern border of the quadrangle. It underlies a low ridge west of the high ridges supported by the Antietam Formation. Due to faulting the lower contact is not exposed; however, in the adjoining Linden quadrangle the contact of the Waynesboro and Shady formations is conformable. The upper contact is placed at the top of the youngest maroon shale beds of the Waynesboro below the green dolomite and dolomitic shale of the Elbrook; the contact of the formations is conformable and transitional. The Waynesboro is exposed in the bluff along the west side of Manassas Run, on the crest of the ridge extending from the Southern Railway northeast of Happy Creek community to the Shenandoah River, and on the low ridges 400 to 600 feet (122 to 183 m) east of the Front Royal town limits near Woodland Park. The thickness is estimated to be about 800 feet (244 m).

Lithologically, the Waynesboro is divided into a lower clastic-carbonate unit, a middle carbonate unit, and an upper clastic unit (Table 1). The lower unit is poorly exposed and incomplete due to faulting. Fragments of maroon, olive, and dark-gray shale; maroon to pale-orange, fine- to medium-grained lithic sandstone and quartz sandstone; and gnarly and oolitic chert are abundant at the surface. One impure limestone exposure occurs along the west side of Manassas Run. The carbonate unit is composed of dark bluish-gray, saccharoidal dolomite; bluish-gray, fine-grained limestone mottled with light-gray, coarse-grained dolomite; and yellow-weathering, medium- to fine-grained, gray dolomite. Lithologies of the upper unit are similar to the lower unit. The bulk of the sandstones are in the lower half of the upper unit. The upper half is composed of maroon and green shales with only minor maroon and rusty-brown sandstones. The upper unit is about 300 feet (91 m) thick and the middle about 400 feet (122 m); only the upper 100 feet (30 m) of the lower unit is present.

Elbrook Formation

The Elbrook Formation is exposed in a broad belt extending from near the northeast corner of the map southwestward to Woodland Park (Plate 1). A small area of the formation is exposed as a fault slice south of Dungadin Heights. Good exposures of the upper part of the formation occur in the valley east of Shenandoah Valley Golf Club. The middle part of the formation is exposed along the Shenandoah River across from Shenandoah Shores and east of the abandoned powerplant. The lower part of the formation is exposed on both sides of the valley parallel to State Road 606 south of Shenandoah Shores.

The lower contact is conformable with the Waynesboro and is placed at the upper, thick maroon shale of the Waynesboro and the lower, green to greenish-gray dolomite and dolomitic shale of the Elbrook. The upper contact is at the base of the lowest sandstone in the Conococheague and is also conformable. The thickness of the Elbrook is about 2,000 feet (610 m).

The lower 300 to 400 feet (91 to 122 m) of the Elbrook is composed of green to greenish-gray, fine-grained dolomite (R-5612), dolomitic limestone, and shale. A thin, rusty brown weathering, calcareous siltstone marks the top of this unit. The bulk of the formation is composed of dark- to medium-gray, fine- to medium-grained limestone, dolomitic limestone, dolomite, and dolomitic shale. Bedding thicknesses vary from 0.5 inch (1.3 cm) to 2 feet (61 cm). The thicker beds weather ribbon-banded and on complete decalcification the dark argillaceous bands yield ocherous, shale-like chips. The thickness of this unit is about 1,200 to 1,300 feet (366 to 396 m). The upper 300-400 feet (91-122 m) of the formation is characterized by interbedded yellow-weathering, light-gray, laminated dolomite and blue, algal limestone.

Conococheague Formation

The Conococheague Formation crops out in a belt extending from the northeast corner of the mapped area southwestward through Front Royal to the entrance to the Shenandoah National Park. Good exposures of the formation may be seen along the bluffs of the Shenandoah River east of Willow Brook, south of Horseshoe Bend, west of the abandoned powerplant and in the fields northeast of Front Royal Junction.

In the Front Royal quadrangle the Conococheague can be divided into four broad lithologic units of unequal thickness. The lower 200 feet (61 m) of the formation is designated the Big Spring Station Member (Wilson, 1952, p. 307-308); sandstone, dolomite, and dolomitic limestone similar to the member as described by Edmundson and Nunan (1973) just to the northwest are present. The lower contact with the Elbrook is mapped at the base of the lowest coarse-grained sandstone of the member. The upper contact is gradational with the overlying limestone of the Conococheague. Lithologically, the Big Spring Station is composed of rusty-weathering, coarse-grained, calcareous sandstone (R-5909) ; bluish-gray, fine-grained, laminated limestone; dark-gray, dolomitic limestone; light-gray, fine-grained dolomite; and intraformational conglomerate. The intraformational conglomerate contains flat, platelike limestone clasts in a fine- to medium-grained limestone matrix with algae and oolites.

Overlying the Big Spring Station Member is a unit about 600 feet (183 m) thick composed mostly of ribbon-banded limestone. The medium gray beds are composed of fine-grained limestone (R-5908). Dark-gray, silty dolomite bands stand out in marked contrast to the medium-gray limestone giving the rock a ribbon-banded appearance. Interbedded with the ribbon-banded limestone are edgewise conglomerate and limestone containing distinct siliceous laminae.

Limestone with abundant siliceous crinkly laminae forms the third unit which is about 800 feet (244 m) thick. The limestone is dark to medium gray and fine grained; siliceous laminae are readily apparent only on weathered surfaces. Thin intraformational conglomerate, ribbon-banded limestone, and medium-gray, medium- to fine-grained dolomite are present.

The bulk of the upper unit is composed of fine-grained, light-gray, laminated dolomite with thin sandstone beds near the top. Interbedded with the dolomite is limestone with siliceous laminae and conglomerate. The upper contact of the Conococheague is placed at the top of the youngest sandstone or dolomite beneath the fossiliferous black limestone of the Stonehenge Formation. The estimated thickness of the Conococheague is 2,300 feet (701 m).

ORDOVICIAN SYSTEM

The oldest Ordovician rocks have generally been mapped as the Beekmantown Formation in Virginia. Sando (1956, 1957), however, defined them in Maryland as the Beekmantown Group that included three formations which are, in ascending order, the Stonehenge Formation, the Rockdale Run Formation, and the Pinesburg Station Dolomite. Edmundson and Nunan (1973) mapped the three formations just to the northeast of the Front Royal quadrangle. They report, however, that the Pinesburg Station is absent in the Boyce and Stephens City quadrangles; it is also absent in the Front Royal quadrangle. It is not known if the Pinesburg Station is lost by lateral facies change, by pinching out, or by erosion.

The younger Ordovician formations (Plate 1) include the New Market Limestone, Lincolnshire Formation, Edinburg Formation, Oranda Formation, and Martinsburg Formation.

Stonehenge Formation

The lower part of the Stonehenge Formation is exposed west of Rockland near the junction of State Roads 658 and 661 in the hanging wall of a reverse fault that parallels Willow Brook (Appendix I, Section 3). The upper part of the Stonehenge is exposed (Figure 7) along State Road 661 beginning at Success and extending 0.5 mile (0.8 km) southeasterly along the road. A small elliptical area of uppermost Stonehenge is exposed 0.4 mile (0.6 km) west of where State Road 658 crosses Willow Brook. A discussion of the Conococheague-Stonehenge contact is given with the Conococheague. The upper contact is placed at the base of the first thick, yellow-weathering dolomite of the Rockdale Run Formation. Interbedded with the dolomite are 4- to 6-inch (10- to 15-cm) -thick beds of gray to white chert.

The lower 100 to 150 feet (30 to 46 m) of the Stonehenge has been termed the Stoufferstown Member (Sando, 1958). Edmundson and Nunan (1973) recognize this unit to the northeast in Clarke County. Lithologically, it consists of fine- to medium-grained, dark-gray to black limestone with thin, sheetlike partings. The partings are crinkly due to a cleavage where the beds have been folded. Thin, coarse-grained, bioclastic limestone is also present.

Above the Stoufferstown Member there is about 500 feet (152 m) of medium- to dark-gray and black, fine- to medium-grained limestone. Near the top of the unit siliceous laminae and algal structures are common.

Good fossils are not common in the Stoufferstown; however, thin beds of macerated fossil debris are common. The following were identified from the upper portion of the Stonehenge: *Fin-*

Figure 7. Stonehenge limestone exposed south of State Road 661, 0.30 mile (0.48 km) southeast of Success.

kelnburgia sp. (brachiopod), *Dakeoceras* sp. (cephalopod), and ?*Eccyliomphalus* sp. (gastropod) (F-892, F-896). Several additional gastropod species were present but were not identifiable. The total thickness is 600 to 650 feet (183 to 198 m).

Rockdale Run Formation

The Rockdale Run Formation is exposed in a broad belt extending southwestward from the Success area through Front Royal to the southwest corner of the map. The upper part of the Rockdale Run is best exposed along Willow Brook 0.5 mile (0.8 km) southeast of Rockland, along the ridge east of Riverton Junction, and in the quarries of the Riverton Corporation (active quarry numbers 6, 16; abandoned quarry numbers 3, 17, 18) (Figure 8). A good section of the formation is exposed on the Shenandoah River east of the Potomac Edison powerplant, which is near the Front Royal Country Club (Appendix I, Sections 1, 2).

Most of the Rockdale Run is composed of bluish- to dove-gray, fine-grained limestone. Mottled and laminated dolomitic limestone and medium-gray, fine- to medium-grained dolomite are present. The mottled beds appear to be anastomosing networks of irregular rodlike bodies of dolomite in fine-grained limestone. Dove-gray

Figure 8. Rockdale Run Formation exposed in active quarry 6 (Plate 1), 0.5 mile (0.8 km) southeast of the intersection of State Road 637 and U. S. Highway 340/522. (Note irregular or pinnacle bedrock profile.)

limestone similar to that found in the New Market is abundant in the upper 300 to 400 feet (91 to 122 m) of the Rockdale Run. Thin lenses of sandstone are found 1,200 feet (366 m) east of the Potomac Edison powerplant and on the ridge north of Rockland and west of Willow Brook. Thin lenses of chert are common near the base of the formation (R-5615).

The thickness of the Rockdale Run is estimated to be 2,400 feet (732 m). Locally, fossils are abundant in limestone beds. *Ceratopea* sp., *Eccyliomphalus* sp., *Hormotoma* sp. (F-895, F-898), *Lecanospira* sp. (F-889, F-894), *Ophileta* sp. (F-899), *Orospira* sp. (gastropods), and large coiled cephalopods (F-893, F-897) were found.

New Market Limestone

The New Market Limestone and overlying Lincolnshire Formation are mapped as a single unit because their outcrop widths are generally too narrow to be shown separately on Plate 1. They outline a major anticline and associated synclines and anticline parallel to U. S. Highway 340/522 north of Interstate Highway 66. Another major anticline outlined by the New Market and

Lincolnshire extends from Kendrick Lane in Front Royal northward to about 0.9 mile (1.4 km) north of the Front Royal Country Club. A third belt of New Market and Lincolnshire extends to the southwest from west of the Skyline Caverns entrance to southwest of Kings Eddy. The lower part of the New Market is well exposed near the farm pond on the west side of the South Fork of the Shenandoah River at Kings Eddy and in the draw across the river to the northeast. Two sections are exposed in an anticline 2.4 miles (3.9 km) south of Cedarville along U. S. Highway 340/522. The thickest New Market is exposed 0.3 mile (0.5 km) east on State Road 675 from the junction with U. S. Highway 340/522.

The New Market unconformably overlies the Rockdale Run. A carbonate-pebble and -cobble conglomerate marks the basal contact of the New Market (Figure 9). A paleosinkhole is exposed 2,000 feet (610 m) N.60°E. of the junction of U. S. Highway 340/522 and State Road 658 at 150 feet (46 m) south of a farm pond. The upper contact is placed at the youngest dove-gray, micritic limestone below dark, medium-grained limestone of the Lincolnshire Formation.

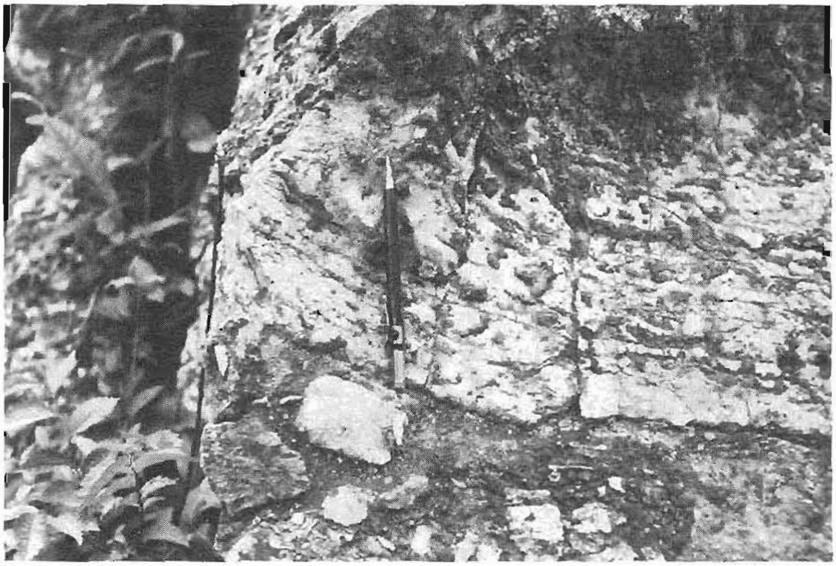

Figure 9. Carbonate pebble conglomerate at the base of the New Market Limestone along West 8th Street, 0.2 mile (0.3 km) southeast of Warren Memorial Hospital.

Throughout most of the area the New Market Limestone can be separated into an upper high-calcium limestone and a lower impure limestone and conglomerate. The lower unit is composed of carbonate-pebble, -cobble, and -boulder conglomerate. The clasts are limestone and dolomite in a coarse sparry calcite matrix. The thickness of the conglomerate varies from a few inches to 20 feet (6 m). Overlying the conglomerate is a series of thin-bedded, argillaceous, gray, fine-grained to aphanic limestones; the thickness varies from a few inches to about 20 feet (6 m).

The upper unit is the high-calcium quarry stone of the Shenandoah Valley. This unit is composed of compact, thick-bedded, bluish- to dove-gray, micritic limestone that breaks with a distinct conchoidal fracture and weathers with a chalklike coating. Small, clear, rhomboid-shaped crystals of calcite are common, giving the limestone a bird's-eye appearance. Generally, this unit contains 97 to 98 percent calcium carbonate (see Economic Geology section for chemical analyses). The thickness of the unit varies from a few inches to 40 feet (12 m).

Because of the unconformable relationship with the Rockdale Run, the thickness of the New Market is highly variable. In the field behind the General Lee Motel, 0.8 mile (1.3 km) north of Cedarville, the New Market is locally less than 5.0 feet (1.5 m) thick. Along State Road 675, 0.3 mile (0.5 km) west of Zion Church, the formation is about 60 feet (18 m) thick. Gastropods resembling the genera *Trechonemella* and *Lophospira* and the small coral *Tetradium syringoporiodes* were found in several localities.

Lincolnshire Formation

The outcrop areas of the Lincolnshire are the same as those outlined for the New Market. The Lincolnshire is well exposed in quarries of the Riverton Corporation (Plate 1, active quarry number 6, abandoned quarry numbers 2, 5); 0.4 mile (0.6 km) east of U. S. Highway 340/522 just north and west of the Shenandoah River; and in the fields east of the General Lee Motel about 1.0 mile (1.6 km) north of Cedarville. The lower contact with the New Market is placed at the top of the youngest, dove-gray, micritic limestone and below the oldest, dark-gray, medium-grained limestone of the Lincolnshire. In some areas the Lincolnshire is overlain by black, fissile shale and in other areas by interbedded black, argillaceous limestone with only minor black shale. The top of the Lincolnshire is mapped at the base of either of the above lithologies.

The principle lithology of the formation is dark- to medium-gray, medium-grained limestone (R-5616). Black and dark-gray, blocky chert nodules and stringers are locally abundant. Interbedded with the dark limestones are thin beds of light-gray, coarse-grained, bioclastic limestone. The thickness of the Lincolnshire varies from about 25 to about 50 feet (8 to 15 m).

Fossils are common to abundant in the Lincolnshire. Ramose bryozoans (F-891), ostracodes, trilobites, crinoid columnals, brachiopods, cephalopods, and algae have been found. *Girvanella* (algae) is so abundant in some beds that they comprise as much as 75 percent of the rock. The brachiopod *Dinorthis atavoides* is a good index fossil for the formation. In the upper 5 to 10 feet (1 to 3 m) of the Lincolnshire large straight cephalopods (?*Orthoceras* spp.) are found; one specimen is about 3 inches (8 cm) in diameter and at least 1 foot (30 cm) long.

Edinburg Formation

The Edinburg Formation is exposed in a northeastward-trending belt from Kings Eddy near the southeast corner to the north-central boundary of the map. North of Riverton the formation parallels U. S. Highway 340/522. The Edinburg is also exposed in a syncline east of Cedarville. The lower contact is placed at the base of the oldest black shale and limestone overlying the granular Lincolnshire. The upper contact is placed at the base of the thin, decalcified Oranda siltstone that underlies black Martinsburg shale.

Black, fissile shale and black to dark-gray, micrograined, blocky- to cobbly-weathering, argillaceous limestone are the dominant lithologies (Figure 10). Thin, dark-gray, brown-weathering siltstone occurs locally. The ratio of shale to limestone in any given exposure is highly variable. The entire Edinburg south of Riverton was considered by Cooper and Cooper (1946, p. 78) to belong to their Liberty Hall facies. North of Riverton thin, medium-grained, cobbly-weathering limestone beds of the Lantz Mills are present (Cooper and Cooper, 1946, p. 78).

East of U. S. Highway 340/522 along the State Road 655 to the Riverton Corporation plant and along Crooked Run, Cooper

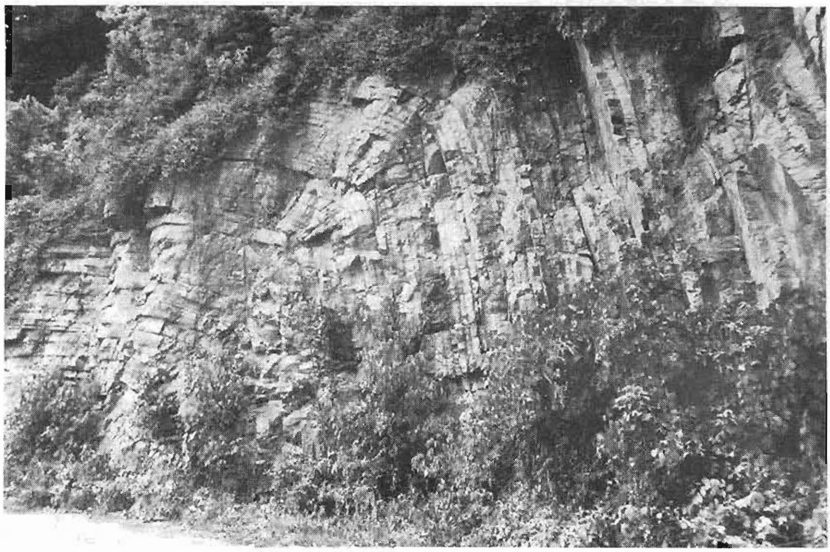

Figure 10. Interbedded limestone (light) and shale (dark) of the Edinburg Formation in roadcut on State Road 679 at junction with State Road 677 (Appendix II, road log cumulative miles 15.0, km 24.1).

and Cooper (1946, p. 94) measured 435 feet (133 m) of Edinburg limestone and shale. This composite section appears to represent a reasonable thickness. Two brachiopod genera, *Corineorthis* and *Resserella* were identified from the area.

Oranda Formation

The Oranda is mapped with the Edinburg Formation because its outcrop width is too narrow to be shown separately on the geologic map (Plate 1). It crops out 0.3 mile (0.5 km) north of the junction of Interstate Highway 66 and U. S. Highway 340/522 and along a farm road 0.8 mile (1.3 km) north of the junction. The Oranda consists of thin, coarse-grained, decalcified siltstone that weathers rusty brown and shaly which lies below the black, calcareous and silty shale of the lower part of the Martinsburg Formation. The thickness does not exceed 15 feet (5 m). Fragmental brachiopod fossils are common and *Cryptolithus* sp. (trilobite) has been collected near the farm road.

Martinsburg Formation

The Martinsburg Formation is exposed in a broad northeastward-trending belt mostly west of Crooked Run and the South

Fork of the Shenandoah River. Along the North Fork the Martinsburg is exposed in a 3-mile (4.8-km)-wide belt. The best outcrops of the formation are along the bluff north of the North Fork, along West Run, and along Punches Run. The base of the Martinsburg is placed at the bottom of the black shale overlying the siltstone of the Oranda (McBride, 1962; McIver, 1970). The upper contact is not present in the area.

Two broad lithologic units are present in the Front Royal quadrangle: (1) the lower 200 to 250 feet (61 to 76 m) of the formation is black, silty, calcareous shale and scattered, thin beds of black, silty, argillaceous, dense limestone (Figure 11) (R-5618); (2) the upper 2,800+ feet (835+ m) is a typical flysch sequence of alternating thin shale and lithic sandstone. The shale is olive green to gray and locally siliceous. The lithic sandstone is greenish gray, rusty weathering, and fine to medium grained. Graded bedding is present. The total thickness of the Martinsburg is estimated to be about 3,000 feet (914 m). The only identifiable fossil was a specimen of *Cryptolithus* cf. *C. tessellatus* (F-890).

Figure 11. Black silty shale of the lower part of the Martinsburg Formation along State Road 627, 0.4 mile (0.6 km) west of Cedarville. (Note southeastward-dipping cleavage which completely obscures bedding; several joint directions are shown.)

QUATERNARY SYSTEM

Surficial deposits can be grouped into four broad types: (1) alluvial roundstone deposits which cap many of the hills (terrace deposits); (2) alluvial flood-plain deposits in the flats along present drainages (alluvium); (3) unconsolidated rock of varying size, lying on steep slopes (colluvium); and (4) sedentary soil. Each of the first three were mapped and the discussion is based on field data. Type four is described in the section on Environmental Geology.

Terrace Deposits

Isolated hills and ridges as well as broad flat areas are covered with a mantle of alluvial terrace deposits consisting of roundstones, sand, silt, and clay of fluvial origin. Roundstones are more abundant in the surface layer (0 to 6 inches or 15 cm). One explanation for this observation is that the finer sand and clay has been removed leaving the coarser material as a winnowed deposit. Three distinct terrace levels are recognized: high, middle, and low. The thickness of terrace deposits at any individual site ranges from 0 to approximately 25 feet (8 m). The high-level terrace deposits are the oldest, and the low-level deposits are the youngest.

High-level terrace deposits: One isolated hill, Catlett Mountain, is all that remains of the highest terrace deposits, which occur at an elevation of 720 feet (220 m) and higher. Pebbles and cobbles of 1 to 5 inches (2 to 13 cm) are abundant in artificial cuts, although the smaller size fraction is less significant in the surface layer. Boulders 1 foot (30 cm) in diameter are abundant in the surface layer. Boulders to 3 feet (1 m) in diameter are common. The matrix material is clay, silt, and fine-grained quartz sand. The framework fragments are composed of quartz sandstone, quartzite, and quartz-pebble conglomerate; several contain *Skolithos.* Boulders of the type described above probably were derived from the Chilhowee Group and the Massanutten Sandstone. (The Massanutten is exposed about 3 miles (5 km) west of Catlett Mountain.)

Middle-level terrace deposits: The middle-level terrace deposits are generally between elevations of 560 and 720 feet (168 and 216 m) above sea level and occur as isolated patches and as continuous sheets along broad, flat-topped ridges (Plate 1). These deposits may best be observed on the east side of Warren Park and at Shenandoah Shores. The roundstones are pebble to cobble in size (1 to 6 inches or 2 to 15 cm) (Figure 12). The composition of the gravels is quartz sandstone and quartzite derived from the Chilhowee Group and the Massanutten Sandstone. Sand, clay, and silt comprise the matrix material.

Southwest of Dungadin Heights two areas of ironstone breccia were mapped separately from the other middle-level terrace deposits (Plate 1). The fragments are angular and range from 0.2 to 10 inches (0.5 to 25 cm) in longest dimension. Iron oxides and silica replaced and cemented the original carbonate and siltstone clasts (R-5610). The quartz crystals have as many as three stages of overgrowths and more than 50 percent of the crystals are doubly terminated. This type of deposit is believed to result from the infiltration of iron- and silica-bearing water into carbonate residuum overlain by gravels.

Low-level terrace deposits: The elevation of the base of the lower terrace ranges from 460 feet (140 m) along the Shenandoah River at the eastern edge of the map to 500 feet (152 m) at Kings Eddy (Figure 13). The maximum upper elevation is 560

Figure 12. Middle-level terrace deposits overlying Martinsburg shale on State Road 619, 0.5 mile (0.8 km) west of junction of State Roads 615 and 619.

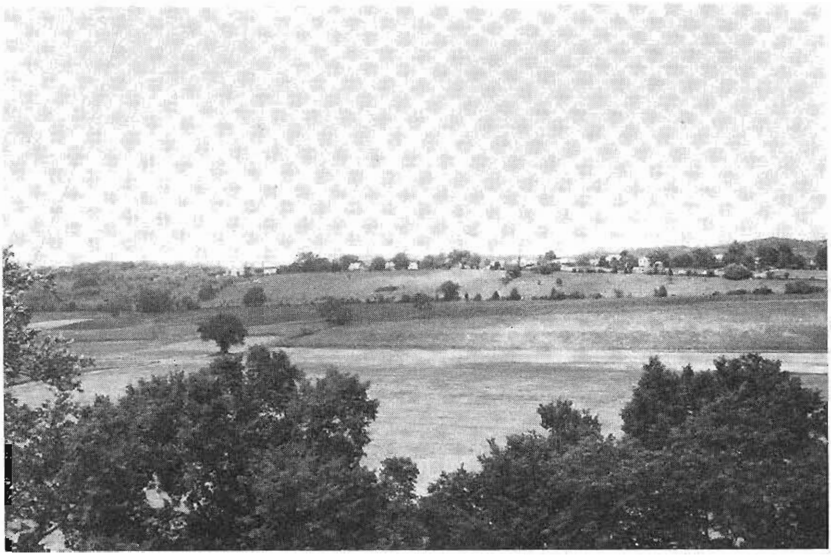

Figure 13. Low-level terrace deposits and flood plain along west bank of the South Fork of Shenandoah River; looking south from U. S. Highway 340/ 522 bridge at Riverton.

feet (171 m). Quartz sandstone and quartzite pebbles and cobbles occur in a matrix of clay and minor quartz sand. Roundstones are abundant only along Manassas Run and the Shenandoah River at the east edge of the mapped area.

Colluvium

Large colluvial deposits occur at the base of the escarpment along the west slope of Dickey Ridge and around Green Hill. Colluvium as used in this report refers to unconsolidated earth materials that have been moved downslope by gravity with no significant fluvial transport. The rock fragments are angular and the composition is closely related to the exposed bedrock. Along the base of Dickey Ridge the slopes are covered with angular boulders of greenstone, granite, unakite, epidote, and flow breccia derived from the Catoctin and Pedlar formations. Near the intersection of U. S. Highway 340 and State Road 607 a remnant of a fan composed of highly weathered greenstone, epidosite, and granite is mapped with the colluvium.

A wide belt of colluvium is exposed around Green Hill and to the northeast, east of State Road 624. The rock fragments are quartzite and quartz sandstone. On the upper slopes of Green Hill the fragments are 1- to 3-inch (3- to 8-cm) cuboidal blocks in a clay-sand matrix (Figure 14). The lower slopes are covered with angular quartzite and iron-cemented fragments that range from 1 inch (2 cm) to more than 1 foot (15 cm) in largest dimension. The thickness of the colluvium is highly variable and is estimated to be 0 to 25 feet (0 to 8 m).

Alluvium

Overbank deposits occur along the Shenandoah River and all of the major tributaries. A broad flood plain is developed along the South Fork of the Shenandoah River west and southwest of Riverton (Figure 13). The deposits are composed of fine-grained, dark-brown quartz sand and silt with minor clay. Fresh-water mollusk shells are common. Roundstones are common to abundant along Happy Creek, Leach Run, Manassas Run, and Sloan Creek. Happy Creek in the town of Front Royal appears to be cutting in an old valley fill of weathered igneous and metamorphic cobbles and boulders (Figure 15).

Figure 14. Colluvium composed of cuboidal quartz sandstone blocks in Green Hill Forest subdivision on the south slope of Green Hill.

Figure 15. Valley fill of igneous and metamorphic roundstones along Happy Creek south of E. 6th Street behind the Pullman Couch Company plant.

STRUCTURE

The Front Royal quadrangle is located midway between the Blue Ridge anticlinorium to the east and the Massanutten synclinorium to the west. The present structural configuration of the rocks is related to compressive forces that produced a westward tectonic transport. The rocks are folded into a series of anticlines and synclines. The west limbs of anticlines and east limbs of synclines are steep to overturned. Five northward-trending reverse faults disrupt the normal stratigraphic sequence. South of Front Royal, faulting has produced a large salient of older rocks of the Blue Ridge province, which are faulted over younger rocks of the Valley and Ridge province. Two well-developed generations of southeastward-dipping cleavage pervades the less competent rock units.

FOLDS

Large north-northeastward-trending asymmetric and overturned folds are the dominant fold features in the Front Royal quadrangle. The Stone Bridge anticline (eastern portion of Plate 1) is restricted to the Elbrook and Waynesboro formations and is overturned from Stone Bridge in the adjoining Boyce quadrangle (Edmundson and Nunan, 1973, Plate 3) southwestward to where it is covered by younger faulting. Each of these formations contain many weak, ductile interbeds of shale and limestone which deform to produce minor subsidiary folds on the limbs of the major folds. Where dolomite interbedded with shaly limestone or calcareous shale is tightly folded the dolomite is commonly brecciated. No evidence of flowage of breccia fragments was seen.

Northwest of Horseshoe Bend is a large anticline which is asymmetrical to the northwest although not overturned. Overturned subsidiary flexural-flow folds are common in the limestones of the Rockdale Run Formation. Northwest of the westernmost fault and parallel to U. S. Highway 340/522 three major folds are present. The easternmost fold (an anticline) involves the Rockdale Run, New Market, and Lincolnshire formations. Most of the eastern limb is truncated by faulting. Between the anticline described above and the anticline which is closest to U. S. Highway 340/522 is a syncline with Edinburg in the major portion of the trough. About 0.5 mile (0.8 km) north of State Road 658 the east limb of the syncline is overturned. North of State Road 675 the New Market and Lincolnshire formations of the eastern limb are truncated by faulting. The anticline which parallels U. S. Highway 340/522 is complicated by a minor anticline and a minor syncline about 1.0 mile (1.6 km) north of Cedarville.

The folding is a flexural-flow type except where thick-bedded dolomites failed by brittle fracture and formed breccia. Spaced cleavage is well developed in all the carbonate units and in the fine-grained clastic beds of the Chilhowee Group. The cleavage has a dip to the southeast, and in units such as the Harpers phyllites crenulated cleavage has developed. Locally, the spaced cleavage has been folded into kink folds with an amplitude of 6 to 10 inches (15 to 25 cm) and a comparable wavelength. The plunge of the kink folds is very steep to the north. Kink folds in Conococheague limestone are exposed 0.4 mile (0.6 km) north of the Happy triangulation station and 0.2 mile (0.3 km) west of active quarry number 7 (Figure 16).

FAULTS

Reverse faulting is the most obvious structural element in the Front Royal quadrangle. Two low-angle (15° to 25°) and two

Figure 16. Kink fold in the Conococheague Formation near active quarry number 7 (Plate 1) south of Interstate Highway 66.

high-angle (60° to 80°) reverse faults cut Precambrian and Lower Cambrian rocks. Two high-angle (70° to 80°) reverse faults and one nearly vertical transverse fault cut the Cambrian and Ordovician carbonates. These faults are described in their probable relative sequence of origin.

In the Green Hill area along the trace of the Happy Creek fault (Wickham, 1972) the Antietam is in contact with the lower clastic member of the Waynesboro Formation. The stratigraphic throw is 1,200 to 1,500 feet (366 to 457 m). Quartzite and quartz sandstone of the Antietem are intensely brecciated along the fault and the breccia is mapped as a separate unit. Two small areas separated from the main breccia occurrence have been mapped. In each of these two areas of brecciation a later emplaced fault sheet appears to truncate the breccia. North of Dungadin Heights Precambrian rocks in the Front Royal thrust sheet overlie the breccia. Just east of Front Royal and south of Woodland Park a fault sheet older than the Front Royal fault but younger than the Happy Creek fault overlies the breccia. Breccia fragments are angular, ranging from 0.25 inch to 1 foot (0.63 to 30 cm) in longest dimension, and are cemented by iron oxides (goethite, limonite, and hematite) (Figure 6). A high-angle reverse fault involving Chilhowee rocks is exposed southeast of Green Hill from the eastern boundary of the map to State Highway 55; it is closely related to the Happy Creek fault. Two additional occurrences of this fault sheet are about 0.5 and 1.0 mile (0.8 and 1.6 km) east of the junction of State Highway 55 and U. S. Highway 522. The fault is exposed along the entrance road to the Green Hill Forest subdivision. North of Valley of Retreat the fault truncates a preexisting anticline of the Weverton Formation. At about 0.5, 1.0, and 2.0 miles (0.8, 1.6, and 3.2 km) east of Front Royal this fault truncates the Happy Creek fault and is truncated by the Front Royal fault.

Two north-northeastward-trending high-angle reverse faults are in rocks of Cambrian and Ordovician age. The easternmost one extends from the northern boundary of the map north of Rockland to 0.5 mile (0.8 km) south of the entrance to the Shenandoah National Park. Along most of its western boundary the Conococheague Formation is faulted against the Rockdale Run Formation. At Rockland an overturned syncline of Stonehenge is faulted against the upper part of the Rockdale Run. The presence of upper Rockdale Run fossils and the absence of the Stonehenge along most of the fault trace provide the evidence of faulting; brecciation was not observed along this fault.

The westernmost high-angle fault extends from the northern boundary of the map, 2 miles (3 km) north of Cedarville, south-southwestward to 0.5 mile (0.8 km) southwest of the entrance to Skyline Caverns. Throughout most of its length the Rockdale Run is faulted onto the Edinburg. The contact between black shale and limestone of the Edinburg and light-colored carbonates of the Rockdale Run is striking. Where the fault extends across Luray Avenue and State Roads 658 and 671 it is well exposed. At one of the old Riverton Corporation quarries (Plate 1, abandoned quarry number 3) the Rockdale Run is faulted onto itself. The hill south of the Front Royal Country Club is a klippe of Rockdale Run carbonate surrounded by similar carbonate. The main fault from which the klippe was derived is exposed along the Norfolk and Western Railway tracks. At the south end of the cut (Figure 17) a flat to northwestward-dipping fault is exposed. This is the fault that underlies the klippe. A pinnacle north of the Riverton Corporation plant is a part of the same klippe. The intervening portion of the klippe has been removed by quarrying.

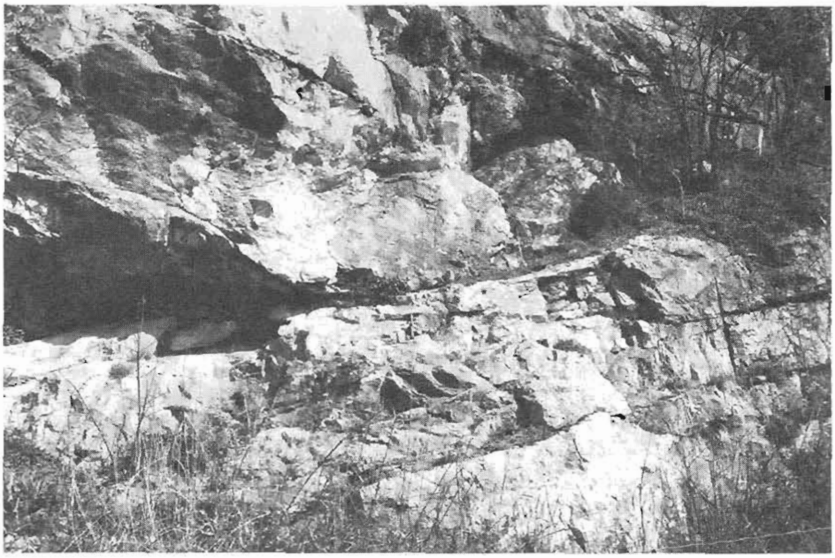

Figure 17. Fault beneath klippe at Riverton Corporation quarry (Plate 1, abandoned quarry number 3); Rockdale Run Formation on both sides of the fault.

The Front Royal fault (Wickham, 1972) has a westerly trend with an arcuate trace from 0.5 mile (0.8 km) east of Valley of Retreat at the east boundary of the map to Front Royal and then southwestward and southward to near the southwest corner of the mapped area. The dip on the fault decreases from nearly vertical at the east boundary to about 15 degrees southeast at Dungadin Heights and southward. East and south of Front Royal the Catoctin Formation forms the leading edge of the fault and truncates older fault blocks. In the Dungadin Heights area the Pedlar Formation forms the leading edge of the fault and truncates the fault breccia unit and Elbrook and Rockdale Run formations. The Elbrook is interpreted as a faulted slice between the Rockdale Run and Pedlar here. The breccia unit may be equivalent to the breccia along the Happy Creek fault, thus representing a fault sheet between the Pedlar and the Rockdale Run.

A high-angle reverse fault of small stratigraphic throw is present in the Catoctin parallel to State Highway 55 near Valley of Retreat. This fault may be related to the Front Royal fault.

Southwest of Riverside a transverse fault with right-lateral displacement was mapped. This fault may have significant vertical movement and be related to en echelon tension fractures in the Rockdale Run and Edinburg formations. These conjugate en echelon tension fractures have been described by Shainin (1950).

ECONOMIC GEOLOGY

Limestone, dolomite, sandstone, and shale are available raw materials. Impure limestone for masonry cement and crushed and broken stone for concrete, road aggregate, railroad ballast, and agricultural limestone are produced in the Front Royal quadrangle. In the past iron, manganese, and copper were produced.

INDUSTRIAL LIMESTONE AND DOLOMITE

Certain uses of limestone and dolomite are dependent upon their chemical composition, whereas other uses are determined by their physical characteristics. Raw materials are present in the Front Royal quadrangle that have the chemical requirements for some of the standardized uses for limestone and dolomite by various consuming industries. These requirements are listed in Table 2.

Carbonate rocks of potential industrial use are roughly subdivided into *high-calcium limestone,* which contains more than 95 percent calcium carbonate; *high magnesium dolomite,* which contains more than 40 percent magnesium carbonate and generally less than 4 percent noncarbonates; *and impure limestone,* a broad term used to describe rocks which are commonly low in magnesium carbonate or contain more than 5 percent noncarbonates. The noncarbonate constituents, chiefly silica, alumina, and iron oxides, are an important consideration in some industrial processes. Chemical analyses (Edmundson, 1945) of samples from the Front Royal quadrangle are shown in Table 3.

HIGH-CALCIUM LIMESTONE

Formations in the mapped area which generally can be classified as high-calcium limestone include the New Market Limestone, the overlying Lincolnshire Formation where free of chert, and locally the upper micrites of the underlying Rockdale Run Formation. Except for an area 0.25 mile (0.40 km) west of Zion Church at the northern edge of the quadrangle where the New Market has a wide outcrop due to structure, the New Market and Lincolnshire areas of exposure are narrow. The variable thick-

Table 2.—Chemical requirements for uses of limestone and dolomite (from O'Neill, B. J., 1964, Table 2).

Uses	Chemical requirements
Lime (calcium)	$CaCO_3$ content not less than 97%, preferably 98% or more.
Steel flux (open hearth)	$CaCO_3$ content should exceed 98%, but some limestone as low as 97% is sometimes accepted.
General chemical use	$CaCO_3$ content should exceed 98%, but limestone as low as 97% is sometimes used.
Glass (calcium)	$CaCO_3$ content should exceed 98% and Fe_2O_3 not more than 0.05%.
Paint and filler	$CaCO_3$ content should exceed 96%; $MgCO_3$ not more than 1%. Other maxima: Fe_2O_3, 0.25%; SiO_2, 2.0%; and SO_3, 0.1%.
Glass (magnesium)	$CaCO_3$-$MgCO_3$ content should exceed 98% and Fe_2O_3 not more than 0.05%.
Refractories	$MgCO_3$ not less than 37.5%. SiO_2, Fe_2O_3, and Al_2O_3 not to exceed 1% each.
Portland cement	$MgCO_3$ not more than 6.3%. Minimum $CaCO_3$ content varies from plant to plant depending on availability of other raw materials.
Lime (magnesium)	$MgCO_3$ content should be between the limits of 21 and 31.5%.
Steel flux (blast furnace)	$MgCO_3$ less than 8% to less than 31%. SiO_2 less than 5%, Al_2O_3 less than 2%. Phosphorous content should not exceed 0.01%.
Agricultural limestone	Minimum of 85% $CaCO_3$.
Agricultural dolomite	$CaCO_3$-$MgCO_3$ content should total at least 85%.

ness of the New Market is due to its deposition upon the irregular paleoerosional surface of the underlying Rockdale Run. Fault blocks also cover the New Market and Lincolnshire formations in a few areas.

The New Market Limestone crops out as a narrow band and the formation is rarely greater than 60 feet (18 m) and mostly about 30 feet (9 m) thick. The outcrop belt forms a sinuous broken pattern due to local structure and extends from the north-central edge to the southwest corner of the mapped area. Table 3 includes chemical analyses of the rocks from the major areas of New Market exposure.

The Lincolnshire Formation is also thin. The chert content varies with the outcrop belt north of Front Royal having much less chert than the belt south of town. The Lincolnshire in the

Table 3.—Chemical composition of carbonate rocks from selected localities in the Front Royal quadrangle (modified after Edmundson, 1945, p. 171-173).

<table>
<tr><th>Location</th><th>Formation</th><th colspan="2">Sampled thickness
in Feet (Meters)</th><th>$CaCO_3$</th><th>$MgCO_3$</th><th>SiO_2</th><th>Fe_2O_3</th><th>Al_2O_3</th><th>Total</th></tr>
<tr><td rowspan="3">Along U. S. Highway 340/ 522 about 1.0 mile (1.6 km) southwest of Nineveh</td><td>Edinburg</td><td>100</td><td>(30)</td><td>88.77</td><td>1.65</td><td>6.51</td><td colspan="2">3.02</td><td>99.95</td></tr>
<tr><td>Lincolnshire</td><td>30</td><td>(9)</td><td>94.20</td><td>2.17</td><td>2.53</td><td colspan="2">0.41</td><td>99.31</td></tr>
<tr><td>New Market</td><td>60</td><td>(18)</td><td>95.04</td><td>3.16</td><td>1.03</td><td colspan="2">0.29</td><td>99.52</td></tr>
<tr><td rowspan="5">East and west of U. S. Highway 340/ 522 at Cedarville</td><td>Edinburg</td><td>385</td><td>(117)</td><td>78.38</td><td>5.13</td><td>16.23</td><td>0.48</td><td>1.45</td><td>101.67</td></tr>
<tr><td>Lincolnshire</td><td>61</td><td>(18)</td><td>86.02</td><td>13.37</td><td>0.80</td><td>0.09</td><td>0.21</td><td>100.49</td></tr>
<tr><td>Rockdale Run</td><td>48</td><td>(14)</td><td>73.92</td><td>21.90</td><td>1.73</td><td>0.28</td><td>0.23</td><td>98.06</td></tr>
<tr><td>Rockdale Run</td><td>50</td><td>(15)</td><td>88.95</td><td>10.71</td><td>0.75</td><td>0.12</td><td>0.54</td><td>101.07</td></tr>
<tr><td>Rockdale Run</td><td>50</td><td>(15)</td><td>94.50</td><td>6.48</td><td>0.47</td><td>0.21</td><td>0.33</td><td>101.99</td></tr>
<tr><td rowspan="4">About 1.0 mile (1.6 km) north of Riverton and 0.25 mile (0.40 km) west of Shenandoah River</td><td>Edinburg</td><td>60</td><td>(18)</td><td>87.84</td><td>1.95</td><td>8.09</td><td>0.57</td><td>1.27</td><td>99.72</td></tr>
<tr><td>Lincolnshire</td><td>20</td><td>(6)</td><td>97.79</td><td>1.95</td><td>0.69</td><td colspan="2">0.34</td><td>100.77</td></tr>
<tr><td>New Market</td><td>28</td><td>(8)</td><td>99.04</td><td>2.10</td><td>0.61</td><td colspan="2">0.37</td><td>102.12</td></tr>
<tr><td>Rockdale Run</td><td>67</td><td>(20)</td><td>73.98</td><td>25.08</td><td>2.10</td><td>0.45</td><td>0.38</td><td>101.99</td></tr>
<tr><td rowspan="2">Riverton Corporation quarry 0.25 mile (0.40 km) northwest of Riverton Junction</td><td>New Market</td><td>40</td><td>(12)</td><td>97.36</td><td>1.64</td><td>0.56</td><td>0.12</td><td>0.30</td><td>99.98</td></tr>
<tr><td>Rockdale Run</td><td>25</td><td>(8)</td><td>89.10</td><td>7.69</td><td>1.42</td><td>0.16</td><td>0.98</td><td>99.35</td></tr>
</table>

Table 3.—Continued

Location	Formation	Sampled thickness in Feet	(Meters)	$CaCO_3$	$MgCO_3$	SiO_2	Fe_2O_3	Al_2O_3	Total
In bluff near Happy Creek 0.25 mile (0.40 km) southeast of Riverton Junction	Rockdale Run	25	(8)	87.00	0.65	11.26	0.23	trace	99.14
	Rockdale Run	25	(8)	86.68	4.25	9.03	0.31	0.24	100.51
	Rockdale Run	25	(8)	88.28	1.95	8.00	0.27	0.29	98.79
	Rockdale Run	25	(8)	85.84	3.62	10.15	0.40	0.55	100.56
	Rockdale Run	25	(8)	87.70	4.23	6.90	0.71	0.11	99.65
Along northwest slope of low ridge between Norfolk and Western Railway and U. S. Highway 340 about 2 miles (3 km) northeast of Karo	New Market	60	(18)	96.70	1.73	0.26	0.08	0.74	99.51
In bluff of Shenandoah River, 2 miles (3 km) southeast of Cedarville	Rockdale Run	160	(49)	78.59	7.87	8.53	1.06	3.07	99.12
	Rockdale Run	60	(18)	81.77	5.04	10.96	0.44	0.58	98.79
	Rockdale Run	60	(18)	79.20	8.35	10.83	0.40	0.76	99.54
	Rockdale Run	60	(18)	85.06	5.33	9.01	0.48	0.78	100.66
	Rockdale Run	60	(18)	84.07	1.17	11.04	0.65	1.32	98.25
	Rockdale Run	60	(18)	78.89	7.95	13.44	1.33	trace	101.61
	Conococheague	75	(23)	80.07	9.90	8.08	1.16	0.13	99.34
	Conococheague	75	(23)	85.11	4.98	9.43	0.56	0.62	100.70

vicinity of Riverton is high-calcium limestone. It and the New Market have been quarried for many years by the Riverton Corporation (Plate 1, active quarry number 6). Several miles farther north the amounts of impure shaly partings increase and the unit generally does not produce high-calcium limestone.

The upper part of the Rockdale Run Formation in the northern part of the quadrangle contains units of high-calcium micritic limestone very similar to the New Market in composition. These limestones are interbedded with dolomites and dolomitic limestones and probably would not be feasible for quarrying for high-calcium purposes.

HIGH-MAGNESIUM DOLOMITE

Available analyses of the formations in the Front Royal quadrangle have shown no rock units which meet the specifications for high-magnesium dolomite. Data is, however, sparse for much of the area, and some of the lower part of the Rockdale Run Formation, the Elbrook Formation, and the Waynesboro Formation contain dolomites that might have sufficient magnesium content though the impurity percentage may be too great. The Shady Formation, which contains a large percentage of high-grade dolomite and which is quarried to the northeast in Clarke County, has been faulted out in the study area.

IMPURE LIMESTONE

Impure limestone formations include the Stonehenge, the Lincolnshire (where not of high-calcium grade), and the Edinburg formations. Other relatively impure limestones interbedded with dolomites are referred to under "Crushed and Broken Stone".

The Stonehenge crops out only in the northern portion of the quadrangle in the plunging anticline between Rockland and Success along State Road 661 and in a faulted syncline at Rockland. This area has not been sampled.

In the Edinburg Formation black limestone is predominant and shale generally consists only of thin interbeds. The formation forms an outcrop belt of approximately 450 feet (137 m) of stratigraphic thickness. It has been quarried for many years at

Riverton by the Riverton Corporation as a major ingredient in masonry cement (Plate 1, active and abandoned quarry numbers 2, 4, 5). The limestone is quarried, crushed, and conveyed to the lime plant where the stone is calcined and hydrated. Then the hydrated lime is conveyed by belt to another building where it is mixed with purchased portland cement to produce the masonry cement.

CRUSHED AND BROKEN STONE

Physical properties are most important when the rock is used for dimension stone, riprap, and crushed stone for construction. The most important use of crushed stone today is highway construction. In order for a material to be utilized for various highway aggregate purposes it must meet certain specifications such as resistance to abrasion, absorption, specific gravity, resistance to freeze-thaw breakdown, and affinity for bituminous material (Gooch, Wood, and Parrott, 1960).

Samples from parts of all the carbonate formations, Chilhowee quartzites, and Catoctin greenstone in adjacent areas to the Front Royal quadrangle were found to have grade A classification (Gooch, Wood, and Parrott, 1960). Physical test results from a statewide survey for potential aggregate sources can be found in Parrott (1954); two limestone outcrops within this study area were among the tested samples showing good potential.

Large amounts of aggregate are produced in the Front Royal area. The Riverton Corporation intermittently operates quarries east of Riverton on both sides of the Shenandoah River (Plate 1, active and abandoned quarry numbers 3, 6, 16, 17, 18). Most of this production is used for concrete and road aggregate, railroad ballast, and agricultural limestone. Several paving companies operate plants at the site and buy sized stone from the Riverton Corporation. The Interstate Stone Corporation operates a crushed stone quarry utilizing Conococheague limestone from east of Front Royal to provide materials for the construction of Interstate 66 (Plate 1, active quarry number 7). Old abandoned quarries are scattered in the area (Plate 1, abandoned quarry numbers 13, 19); these were small operations usually opened for a specific project and worked with a portable crusher. The Norfolk and Western Railway and the State Department of Highways were the principal operators.

HIGH-SILICA SAND

The Antietam Formation is the only unit in the mapped area that has potential use as high-silica sand. The sandstone is generally quite pure, but the sand grains are cemented with silica and commonly pressure-welded, which makes the rock expensive to crush. Hardness varies in the unit but secondary iron and manganese mineralization make it unsuitable for high-silica needs. The Southern Railway operated a small quarry (Plate 1, abandoned quarry number 9) in the Antietam Formation on the northeast end of Green Hill which provided a source for ballast. The natural bedding, jointing, and fractures facilitated relatively easy removal.

CLAY, SHALE, AND RELATED MATERIAL

Tests and determinations of properties required to evaluate the potential ceramic and nonceramic uses of raw materials in Warren County have been published by Ries and Somers (1920) and Calver, Hamlin, and Wood (1961). The tests are summarized in Table 4.

SAND AND GRAVEL

There are at present no known active sand and gravel operations in the mapped area. Potential for small localized operations exist in the eastern portion of the quadrangle in the terrace and flood-plain deposits along the Shenandoah River and Manassas Run, and in the colluvium on the northwest side of Green Hill. Most of these deposits are rather thin, averaging only about 10 feet (3 m). They are composed of quartzite boulders in a sandy soil matrix and were derived from the Cambrian Chilhowee Group to the east or the Silurian Massanutten Formation to the west.

The area of Front Royal in the valley between the ridge on which Randolph Macon Military Academy is situated and the higher elevated residential areas adjacent to and including Woodland Park is in the flood plain of Happy Creek. The gravel cover in this area is extensive and thick in some places. Exposures on the banks of Happy Creek and on the east side of the Pullman Couch Plant parking lot give some indication of the material that is present. Most of these gravels originate in the Blue Ridge to the south and are primarily of igneous composition. They generally weather and disintegrate too rapidly to be of value as gravel materials.

Table 4.—Potential uses of clay and shale from the Front Royal quadrangle.

Location	Formation	Sampled interval	Potential use
Just behind Riverton railroad station[1]	Edinburg?	Reddish-brown residual clay; abundant quartz grains; kaolinite and hydromica.	Common brick
North side of State Highway 55 approximately 1.0 mile (1.6 km) west of Riverton (repository number R-649)[2]	Martinsburg	Outcrop of pale and dark yellowish-orange shale and interbedded layers of fine-grained sandstone.	Common brick and tile

[1]Modified after Ries and Somers (1920). [2]Modified after Calver, Hamlin, and Wood (1961); sample on file in the Virginia Division of Mineral Resources repository where it is available for examination.

IRON AND MANGANESE

Mines and prospects of iron and manganese oxides have been described from many localities along the northwestern foot of the Blue Ridge (Watson, 1907; Stose and others, 1919). Seibel Iron Mines, Inc., of Philadelphia was actively mining both commodities in eastern Warren County in the early twentieth century.

The iron ore of Warren County was classed by Holden (1907) as "Blue Ridge Limonite Ore". It occurs along the Happy Creek fault on the western side of Green Hill and forms a breccia cement in the Antietam quartzite. The iron was probably leached from surrounding rocks, carried in solution by circulating surface or ground waters, and eventually precipitated into the cavities formed by the brecciation. This association with the quartzite was the major obstacle to mining the ore. Large amounts of silica not only reduced the percentage of iron in the ore but also reduced the production of the furnace by requiring more lime to be used to flux out the silica. The Happy Creek mines were located 2 miles (3 km) southeast of Front Royal at the southwest end of

Green Hill (Plate 1, abandoned mine numbers 10, 11). The ore was washed at the site and transported by narrow-gauge railway to Happy Creek Station for shipment. In 1907, operator H. N. Seibel reported production of three cars per day with metallic iron content of 49.48 percent. Today, only the open pits remain to be seen at the site though the roadbed of the railroad can still be traced around Green Hill.

Although most of the manganese deposits of the Blue Ridge region do not appear large, many occurrences are known and in aggregate they possibly could produce commercial quantities of ore. In the Warren County area one manganese mine was worked for several years beginning in 1907; the Happy Creek or Seibel Mine (Plate 1, abandoned mine number 8) was located 3 miles (5 km) east of Front Royal on the northwest side of Green Hill. Most of the manganese oxides occur in residual clay. Manganese-iron nodules, up to 8 inches (20 cm) in diameter, are disseminated through the clay in varying concentrations (R-4381, R-5609). This mode of occurrence required that the ore be milled and washed to separate the nodules from the clay. The mill was located near Happy Creek Station approximately 0.5 mile (0.8 km) from the mine and was connected to the mine by a narrow-gauge tramway. The richest zones of the mine yielded one ton of nodules for every 8 cubic yards (6 cu m) of material. If the proportion of limonite (iron) was too great a mixed iron and manganese product was shipped and the yield was 1 ton of ore per 3 cubic yards of clay. The plant produced, at its peak, 300 tons (272 M.T.) of washed ore per month. Most of the ore contained 20 percent manganese, 21 percent iron, and 12-15 percent silica, though some lots contained as much as 38 percent manganese (Stose, and others, 1917). In other areas the Antietam outcrops show iron and manganese staining but no other prospects are known to have been worked.

COPPER

In the early 1900's the Virginia and Pittsburgh Copper Company owned several mines and prospects on Dickey Ridge (Plate 1, prospect numbers 12, 14). One of the mines, Gooney-Manor mine, was located 0.5 mile (0.8 km) southwest of Dungadin Heights (Plate 1, abandoned mine number 15). The copper mineralization occurs in this area along crevices and shear planes formed by the faulting which brought the igneous basement rocks into contact with the Ordovician limestones. It is believed that the ores were formed by a concentration of material leached out of locally copper-rich portions of igneous rocks. The shear zones have afforded a place for the gathering of these solutions and the deposition of material. The Gooney-Manor mineralization was described as "a lens-shaped ore body at the contact of the porphyry and limestone." Sulfides were found at a depth of 350 feet (107 m) in a 7-foot (2-m) -thick ore body that was traced 800 feet (244 m) along strike. Native copper, other copper sulfides, and traces of gold and silver were noted. In 1909 several carloads of material from the mine assayed at 5 percent (Luttrell, 1966, p. 54). The ruins of the crusher and remains of some trench mines can still be seen at the site.

Along the west slope of Dickey Ridge several abandoned prospect pits were found. In one pit the secondary copper minerals malachite and azurite were collected (R-5600).

HYDROGEOLOGY

By Richard H. DeKay

Hundreds of dug, bored, and drilled water wells have been constructed in the Front Royal quadrangle, and records for many have been furnished to the Division of Mineral Resources (Table 5). Additional information has been obtained from Larry LeHew, Donald Russell, C. E. Shirley and C. R. Totten, well drillers who were generous with their time and knowledge of local drilling conditions. The main problem in synthesizing these data is the lack of complete records for the domestic and farm wells that constitute about 90 percent of all water-well drilling operations. Seldom are records kept of the depth at which water-bearing fractures are encountered, and few pump tests or water analyses are made for other than public and industrial wells. As a result the most productive depth zones are not established with certainty, and little is known of the capacity yield of wells or the mineral content of the water. Nevertheless, with the cooperation of the well drillers, the county and state health departments, and the State Water Control Board sufficient information has been assembled to develop a basic understanding of the general ground-water conditions in the Front Royal quadrangle.

The 15 formations that have been identified as the rock units that constitute bedrock in the quadrangle (Plate 1) may be

Table 5.—Wells drilled to water in the Front Royal quadrangle.

Well No.[1]	Owner	Driller	Water-bearing formation	Water-bearing lithology	Depth (feet)	Depth (meters)	Yield (gpm)[3]	Yield (l/m)[3]
1	A. Britt	D. Russell	Conococheague	Limestone	130	40	12	45
2	Shenandoah Valley Country Club	D. Russell	Conococheague	Limestone	100	30	200	757
3	Shenandoah Valley Country Club	D. Russell	Conococheague	Limestone	265	81	150	568
4	T. Sowers[2]	J. Rinker	Rockdale Run	Limestone	220	67	13	49
5	G. Lee[2]	J. Rinker	Stonehenge	Limestone	182	55	1	4
6	T. Covel	———	Stonehenge	Limestone	115	35	12	45
7	R. Stansfield	L. LeHew	Rockdale Run	Limestone	150	46	50	189
8	H. Horton	D. Russell	Rockdale Run	Limestone	250	76	3	11
9	E. Smedley	D. Russell	Edinburg	Limestone	84	26	20	76
10	T. Patterson	L. LeHew	Rockdale Run	Limestone	310	94	4	15
11	H. Nailer[2]	J. Rinker	Rockdale Run	Limestone	42	13	12	45
12	C. Donovan[2]	J. Totten	Rockdale Run	Limestone	78	24	10	38
13	J. Beatty[2]	J. Rinker	Martinsburg	Shale	104	32	3	11
14	J. Rinker[2]	J. Rinker	Martinsburg	Shale	74	23	1	4
15	Dept. Highways	Sydnor	Martinsburg	Shale	166	51	67	254
16	A. Cox	J. Totten	Martinsburg	Shale	83	25	5	19
17	Elks Home	L. LeHew	Martinsburg	Shale	270	82	40	151
18	M. Duck[2]	J. Totten	Edinburg	Limestone	125	38	30	114
19	J. Totten[2]	J. Totten	Martinsburg	Shale	67	20	1	4
20	J. Totten[2]	J. Totten	Martinsburg	Shale	87	27	10	38
21	School Board[2]	J. Totten	Martinsburg	Shale	87	27	10	38
22	Dr. King[2]	J. Totten	Martinsburg	Shale	78	24	30	114
23	G. Catlett[2]	J. Totten	Martinsburg	Shale	57	17	12	45

Table 5.—Continued

Well No.[1]	Owner	Driller	Water-bearing formation	Water-bearing lithology	Depth (feet)	Depth (meters)	Yield (gpm)[3]	Yield (l/m)[3]
24	D. Chaffin	D. Russell	Martinsburg	Shale	100	30	100	379
25	A. Fletcher	L. LeHew	Martinsburg	Shale	150	46	50	189
26	Livestock Mkt.	L. LeHew	Martinsburg	Shale	165	50	100	378
27	C. Good	L. LeHew	Martinsburg	Shale	120	37	80	303
28	G. Gerlick	D. Russell	Rockdale Run	Limestone	325	99	25	95
29	Dungadin 1	C. Shirley	Pedlar	Granite	198	60	—	—
30	Dungadin 2	C. Shirley	Rockdale Run	Limestone	398	121	—	—
31	Dungadin 3	C. Shirley	Rockdale Run	Limestone	505	154	1	4
32	Dungadin 4	C. Shirley	Pedlar	Granite	520	158	3	11
33	Dungadin 5	C. Shirley	Pedlar	Granite	132	40	0	0
34	KOA 1	D. Russell	Rockdale Run	Limestone	505	154	0	0
35	KOA 2	D. Russell	Rockdale Run	Limestone	400	122	0	0
36	KOA 3	D. Russell	Rockdale Run	Limestone	200	61	0	0
37	KOA 4	D. Russell	Pedlar	Granite	300	91	0	0
38	KOA 5	D. Russell	Pedlar	Granite	400	122	2	8
39	KOA 6	L. LeHew	Pedlar	Granite	220	67	2	8
40	KOA 7	C. Shirley	Rockdale Run	Limestone	160	49	25+	95+
41	W. Bowle	———	Pedlar	Granite	218	66	3	11
42	E. Benger	———	Pedlar	Granite	75	23	4	15
43	M. Kidwel	———	Pedlar	Granite	39	12	20	76
44	M. Hitt	C. Hopkins	Pedlar	Granite	90	27	7	26
45	S. Payne 2	———	Pedlar	Granite	96	29	10	38
46	S. Payne 1	———	Pedlar	Granite	275	84	1	4
47	E. Williams	H. Stribling	Rockdale Run	Limestone	500	152	2	8
48	G. Waller[2]	J. Totten	Edinburg	Limestone	48	15	8	30

Table 5.—Continued

Well No.[1]	Owner	Driller	Water-bearing formation	Water-bearing lithology	Depth (feet)	Depth (meters)	Yield (gpm)[3]	Yield (l/m)[3]
49	Viscose 2	V. Mach	Edinburg	Limestone	580+	177+	200	757
50	Viscose 1	V. Mach	Martinsburg	Shale	1345	410	120	454
51	J. Marshall[2]	J. Rinker	Edinburg	Limestone	147	45	12	45
52	M. Craig[2]	C. Fisher	Rockdale Run	Limestone	75	23	3	11
53	Ice Plant[2]	J. Totten	Rockdale Run	Limestone	125	38	20	76
54	Cold Storage[2]	J. Totten	Rockdale Run	Limestone	87	27	20	76
55	J. Cameron[2]	J. Totten	Rockdale Run	Limestone	48	15	20	76
56	H. Seibell[2]	J. Totten	Conococheague	Limestone	519	158	100+	379+
57	Col. Miller[2]	J. Totten	Elbrook	Dolomite	78	24	30	114
58	Dr. Kipps[2]	J. Totten	Elbrook	Dolomite	327	100	1	4
59	H. DeNeal	D. Russell	Waynesboro	Shale	300	91	16	61
60	G. Alexander	L. LeHew	Waynesboro	Shale	210	64	6	23
61	H. Compton[2]	J. Totten	Waynesboro	Shale	45	14	10	38
62	Deerflinger	D. Russell	Elbrook	Dolomite	115	35	7	26
63	D. Turner	D. Russell	Elbrook	Dolomite	400	122	1	4
64	Shenandoah Shores 2	C. Shirley	Elbrook	Dolomite	360	110	35	132
65	Shenandoah Shores 1	H. Stribling	Elbrook	Dolomite	285	87	60	227
66	Shenandoah Shores 3	C. Shirley	Conococheague	Limestone	240	73	70	265
67	Shenandoah River Estate 1	———	Rockdale Run	Limestone	235	72	20	76
68	Shenandoah River Estate 2	———	Rockdale Run	Limestone	285	87	20	76

Table 5.—Continued

Well No.[1]	Owner	Driller	Water-bearing formation	Water-bearing lithology	Depth (feet)	Depth (meters)	Yield (gpm)[3]	Yield (l/m)[3]
69	Fox Hollow 1	F. Martin	Catoctin	Basalt	200	61	2	8
70	Fox Hollow 2	F. Martin	Catoctin	Basalt	300	91	1	4
71	Happy Creek Mining Co.[2]	J. Totten	Catoctin	Basalt	80	24	18	68
72	Canine Center	Leazer	Catoctin	Basalt	300	91	17	64
73	VPI Sta. 1	———	Catoctin	Basalt	150	46	50	189
74	VPI Sta. 2	———	Catoctin	Basalt	250	76	20	76
75	Lake Royal	G. Burner	Catoctin	Basalt	95	29	25	95
76	E. Powell	L. LeHew	Catoctin	Basalt	150	46	15	57
77	High Knob	C. Shirley	Catoctin	Basalt	520	158	0.25	0.94

[1]Well locations plotted on Plate 2.
[2]Data from Virginia Division of Mineral Resources Bulletin 45.
[3]Measurement: gpm, gallons per minute; l/m, liters per minute.

grouped into three types insofar as their water-bearing properties are concerned. The five shale and sandstone formations form the clastic sedimentary rocks that generally are consistent producers of small to moderate well yields from intermediate depths. The eight limestone and dolomite formations make up the carbonate rocks that generally have the widest range in well depths and yields. The third group consists of igneous rocks that are composed of granite and basalt formations which commonly furnish only small quantities of water to relatively shallow wells. Records of wells drilled in each of these major rock types show a range in construction and production statistics that reflect the effects of local drainage, topography, and rock structure. In the Front Royal quadrangle these effects have partially negated any distinctive water-bearing characteristics of the three rock types, altering their hydrogeologic properties until the data for some wells are quite atypical for the type in which they are drilled. It should also be noted that the data on which this report is based are for wells drilled at sites selected for convenience and not their hydrogeologic favorability.

QUANTITY

Past workers such as Cady (1936) considered the carbonate formations as the most favorable producers of ground water in Warren County, and in the Front Royal area the Beekmantown Formation (Rockdale Run in this report) was said to be the best. The granite and basalt of the igneous rocks were established as containing the least favorable aquifers. The clastic shale and sandstone rocks were classified in between, but more similar to the igneous rocks insofar as their water-bearing capacities were concerned. Table 6, however, shows the mitigating effect of local hydrogeologic conditions on the productivity of wells in all types of rocks. Of the 25 wells drilled in the Conococheague (carbonate), Oranda-Edinburg (part carbonate, part clastic) and Martinsburg (clastic) formations there is little to choose from in terms of overall productivity. Cumulatively, the yields range from 1 to 200 gallons per minute (gpm) or 4 to 757 liters per minute (l/m), with the largest individual yield from a well in Conococheague limestone. The 35 wells in the carbonate Elbrook and Rockdale Run formations and the igneous Catoctin Formation have individual yields between 1 and 60 gpm (4 and 227 l/m); the largest of these is from a well in dolomite of the El-

Table 6.—Summary of results for 77 wells drilled for water in the Front Royal quadrangle.

Rock type	Formation penetrated by wells	No. of wells	Yield range (gpm)[1]	Yield range (l/m)[1]	Median yield (gpm)[1]	Median yield (l/m)[1]	Depth range (feet)	Depth range (meters)	Median depth (feet)	Median depth (meters)
Clastic	Martinsburg	15	1-120	4-454	30	114	57-1345	17-410	100	30
	Waynesboro	3	6-16	23-61	10	38	45-300	14-91	210	64
Carbonate	Edinburg-Oranda	5	8-200	30-757	20	76	48-580	15-177	125	38
	Rockdale Run	20	0-50	0-189	10	38	42-505	13-154	227	69
	Stonehenge	2	1-12	4-45	7	26	115-182	35-55	148	45
	Conococheague	5	12-200	46-757	100	378	100-519	30-158	240	73
	Elbrook	6	1-60	4-227	19	72	78-400	24-122	306	93
Igneous	Catoctin	9	1-50	4-189	17	64	80-520	24-158	200	61
	Pedlar	12	0-20	0-76	3	11	39-520	12-158	208	63

[1]Measurement: gpm, gallons per minute; l/m, liters per minute.

brook Formation that yields only 10 gpm (38 l/m) more than the best wells in the Rockdale Run and Catoctin formations. Pedlar granite furnished the smallest yields, producing only 1 to 20 gpm (4 to 76 l/m) from 11 wells, 8 of which yielded less than 5 gpm (19 l/m). Only five records were obtained for wells that obtained water from the clastic Waynesboro and carbonate Stonehenge formations, and no data at all are available for wells in the carbonate Lincolnshire and New Market and clastic Harpers, Antietam and Weverton formations. The five reported yields were from 1 to 16 gpm (4 to 61 l/m), probably a fair appraisal of the water-bearing potential of these seven formations in this quadrangle.

Although a scarcity of records for wells in portions of the quadrangle may have subjugated some of the formations to yield speculations less than will be eventually realized, two overall factors seem to have been established: most of the ground water is available from depths of less than 300 feet (91 m) and wells in the carbonate rocks are generally deeper than those in the clastic and igneous formations. Of the 77 wells for which records are available, 17 are deeper than 300 feet (91 m); of these 17 wells only 5 yield more than 5 gpm (19 l/m), and a deep aquifer is substantiated in only one of these. The water-bearing zones are primarily bedding- and cleavage-plane openings in the clastic rocks, but they are fracture and solution openings in the carbonates. Because of the relative incompetence of the clastic rocks, the numerous but small water-bearing openings are pressed shut by weight of the overburden below a depth of about 200 feet (61 m), whereas fractures and solution cavities generally occur to much greater depths in the carbonates. Water-bearing zones in the igneous rocks are limited to fractures that generally occur at depths of less than 200 feet (61 m) because of the massive, resistant nature of the basalt and granite.

QUALITY

Only 10 chemical analyses of well water are available and those are for wells in only 5 of the 15 rock formations (Table 7). Unfortunately, none of these analyses are of ground water from any of the five clastic rock units, and only one analysis was made of water from each of the basalt and granite formations. Ground water from the carbonate rocks usually has a moderately high calcium-magnesium hardness and a basic pH. If there is a chemical problem with water from the carbonate formations other than hardness, it would appear to be from iron and turbidity. Because of the scarcity of data the source of these constituents cannot be positively identified, but it seems probable that they are derived from heterogeneous sediments that frequently fill solution openings or from mineralized portions of crushed fracture zones. In any case it has been observed that proper well construction and development may reduce or eliminate the iron and turbidity problems soon after a new well is completed. The analyses of water from a basalt and granite well indicate the chemical quality of ground water from the igneous rocks is the best of any in the quadrangle; in a few wells the iron or manganese content may be slightly high, but otherwise the water can be used for most purposes without treatment.

The chemical quality of the ground water in the clastic formations seems to be relatively uniform although no water analyses are available. With few exceptions the water is reported to be moderately soft to moderately hard, but turbidity is a frequent problem due to the incompetent nature of the shales and sandstones that support the open well bore. The dissolution of iron-sulfide minerals in the Martinsburg shale that underlies the northwestern third of the quadrangle causes the ground water to generally be irony and commonly acidic, and sometimes smell of hydrogen sulfide. It is reported (personal communication, C. R. Totten) that water from the abandoned Guard Hill meat-packing plant near the intersection of State Roads 609 and 637 was so acid that plastic pipe had to be used instead of the usual steel casing. Ferromagnesium mineralization in the lower Cambrian clastics that occurs in the east-central portion of the quadrangle accounts for the iron content of waters from these sandstones and siltstones, the friable nature of which is probably the reason coarse sediment and turbid water is present in some wells in this area.

Analyses of water samples from six springs in igneous rocks (Table 7) show the excellent chemical quality of these waters. The three springs at High Knob on the east quadrangle line south of State Highway 55 furnish basic, very soft water that is low in mineralization. Water from the three Dungadin springs in the southwest corner of the quadrangle is of neutral pH, soft, and low in mineral content.

Table 7.—Chemical analyses of water from selected wells and springs in the Front Royal quadrangle. (All measurements are in mg/l except pH.

Well or Spring No.	[1]12	[4]29	[4]29a	[4]29b	[4]29c	[4]30	[1]52	[3]64	[3]65	[3]66	[4]67	[4]68	[2]69	[4]77a	[4]77b	[4]77c
pH	—	7.6	7.0	6.9	6.8	8.2	—	7.3	7.1	7.6	7.8	7.7	7.0	7.3	7.4	7.6
Total Hardness	352.0	41.0	67.0	23.0	26.0	195.0	18.0	481.6	353.6	384.0	276.0	276.0	20.0	17.0	16.0	29.0
Calcium Hardness	—	14.0	21.7	7.1	9.8	117.4	—	—	—	—	174.8	209.1	—	12.0	10.0	20.3
Iron	5.20	0.45	0.08	0.03	0.91	0.89	5.00	0.15	0.04	0.17	0.02	0.03	0.00	0.04	0.16	0.02
Silica	6.8	30.0	27.2	32.4	31.6	23.2	—	11.9	4.4	9.0	—	—	6.6	—	—	16.4
Sulphate	35.0	8.1	6.8	7.3	2.6	9.5	2.0	79.4	15.3	14.8	42.0	22.0	0.0	1.9	2.1	0.3
Nitrate	49.0	2.8	2.7	4.9	5.3	2.0	7.1	6.2	0.5	0.0	3.7	11.3	0.0	3.2	3.1	3.3
Manganese	—	0.01	0.01	0.01	0.02	0.03	—	0.02	0.02	0.00	0.01	0.02	0.25	0.01	0.01	0.03
Calcium	100.0	5.6	8.7	2.8	3.9	47.0	4.0	100.6	116.6	65.0	70.0	83.8	—	4.8	4.0	8.1
Sodium, Potassium	29.7	6.3	7.0	6.7	5.6	6.3	3.4	1.1	1.7	6.5	27.7	3.6	—	1.9	1.8	2.5
Bicarbonate	349.0	—	—	—	—	—	20.0	453.8	392.8	456.3	—	—	—	—	—	—
Chloride	28.0	3.0	8.0	2.0	2.0	2.5	0.08	10.0	10.0	6.0	0.5	0.4	—	1.0	1.0	2.1
Fluoride	—	0.14	0.12	0.11	0.07	0.18	—	0.95	0.10	1.36	0.86	0.17	—	0.10	0.10	—
Magnesium	25.0	5.3	11.6	3.9	3.9	20.4	—	56.0	15.2	54.0	32.0	29.3	—	1.2	1.5	2.2
Free CO_2	—	—	—	—	—	—	—	46.0	50.0	24.0	—	—	—	—	—	—
Copper	—	0.02	0.01	0.01	0.01	0.01	—	—	—	—	0.01	0.00	—	0.01	0.01	0.01
Mineral Residue	—	87.0	166.0	111.0	129.0	321.0	—	474.0	309.0	244.0	420.0	431.0	—	33.0	33.0	52.0

[1]U. S. Geological Survey.
[2]Virginia Division of Mineral Resources.
[3]Froehling and Robertson, Incorporated, Richmond, Virginia.
[4]Virginia Department of Health.

DEPTH OF WELLS

As most of the wells are for small domestic- or farm-water supplies, most are completed at depths of less than 200 feet (61 m). This is particularly evident in the areas underlain by the Catoctin, Pedlar, and Martinsburg formations and may be true for the Lower Cambrian formations for which very little well data is available. Also, some small water supplies have been obtained at relatively shallow depths in the carbonate rocks, but not nearly as commonly as in the clastic and igneous ones. Drilling depths for moderate to large quantities of water are dependent upon a combination of hydrogeologic factors that vary from one locality to another. Generally, the largest yields have been obtained at depths of less than 150 feet (46 m) in the igneous rocks, 200 feet (61 m) in the clastic rocks, and 300 feet (91 m) in the carbonate rocks (Table 6). Some records are available that show the deepest wells are the largest producers, e.g. the 1345-foot (410 m) well that yields 120 gpm (456 l/m) and the 580-foot (177 m) well that pumps 200 gpm (760 l/m). Unfortunately, the depth of the aquifer zones in these wells is not known, but it is very likely that most of the water was obtained at relatively shallow depths and drilling was continued in hopes of encountering more. The fact that less than 5 gpm (19 l/m) was obtained from the deepest wells in 7 of the 12 formations for which records are available shows the futility of drilling deeper than 300 feet (91 m) in most instances.

CONSTRUCTION AND DEVELOPMENT

Construction of water wells is a relatively uncomplicated procedure where the soil and partially weathered rock cover is less than 30 feet thick in most places. A hole is drilled through the overburden and steel casing installed to prevent unconsolidated material from collapsing into the well bore. The remainder of the well is an "open hole" unless broken-rock zones or mud seams in the bedrock require extra casing to buttress the unstable portions of the rock wall. Drilling is generally accomplished by an air-rotary rig that penetrates rock considerably faster than cable-tool equipment, but certain conditions such as thick terrace gravels, bouldery overburden, shattered-rock zones, solution cavities, and steeply inclined strata may cause loss of air pressure or crooked holes and require the use of a cable-tool rig. Casing is always necessary to exclude the loose surface materials from the drill hole, and if the water is for human consumption the casing should be grouted (cemented) in the well bore from bedrock to ground surface to prevent any contaminated near-surface water from entering the well.

Development procedures may be more complex, depending on the hydrogeologic conditions. Drilling is frequently terminated before an adequate amount of water has been obtained, and one of several options is then employed to convert the drill hole into a well. The most obvious is to continue drilling "a little deeper"; in some circumstances this might be worthwhile, but for most hydrogeologic conditions in the Front Royal quadrangle 300 feet (91 m) is deep enough. Another developmental procedure is surging by use of a surge block or air pressure; moderate success is reported for this method, but the increase in yield is generally small. Two other ways to influence well yields are by acidizing and dynamiting the well bore; each has been tried sparingly in northern Virginia with virtually no success. The most common well-development procedure is by pump, or air-lift tests, particularly in areas of carbonate rocks where solution and fracture openings are generally filled to some extent with sediment. Several potentially good wells may have been prematurely abandoned because the air-lift development (thick sediment would ruin a pump) was of too short duration. However, extended pump or air-lift tests should be conducted with great caution in carbonate areas and in ungrouted wells with shallow aquifer zones because the removal of large volumes of mud and gravel from the subsurface may create the unwanted development of sinkholes in the vicinity of the well.

Several factors may currently be contributing to the degradation of local ground-water supplies in the Front Royal quadrangle. It has been stated in one report (EcolSciences, Inc., 1974) that the quality of ground water in and surrounding Front Royal is endangered by the discharge of untreated industrial waste water into South Fork of Shenandoah River, by sewage disposal plants on South Fork of Shenandoah River and Happy Creek, and a very high incidence of septic-tank failure in many communities and developments surrounding the town. The malfunctioning of septic systems was blamed on poor soil conditions; all 14 soil series have moderate or severe restrictions for septic tanks and sewage lagoons, as do all but two for sanitary landfills (EcolSciences, Inc., 1974, p. 27). If sanitary landfills and sludge disposal by land-spreading are used in the future, the quality of ground water may be subjected to further contamination, particularly in areas of carbonate rocks. Hence, the proper location, construction, development, and testing of water wells is of paramount importance.

ENVIRONMENTAL GEOLOGY

The geology of a region involves studies of the physical, mineralogical, and chemical characteristics of the rocks and their stratigraphic relationships, structural attitude, and economic potential. Environmental geology may be defined as the application of geologic factors and principles to the problems created by human occupancy and use of the physical environment. To produce an overall long-range plan for the most efficient and beneficial use of the land, all factors of environmental science must be considered.[1]

The basic human requirements for food and shelter must be available from the physical environment. Areas where food can be found or produced depend on a variety of factors such as kind of soil; physical and chemical properties of the bedrock; presence, quality, and quantity of water; climate; and the topography of the land's surface.

Living in a modern civilization requires mineral resources, stable building sites, and waste disposal capability. To the older necessities, modern man has added the desire for recreational facilities with their special environmental problems.

An environmental geology map (Plate 2) that delineates units with similar properties of the residuum and bedrock in the Front Royal quadrangle was prepared by grouping together lithologic units which could have similar responses to human occupation. Observed lithology, slope stability, joints, and erodibility, were considered when compiling the map. Geologic data was obtained during field work for the preparation of the geologic map (Plate

[1]Additional data on soils, water, regional planning, and forestry may be obtained from the following agencies: (1) Soil Conservation Service, U. S. Department of Agriculture, P. O. Box 10026, Richmond, VA 23240; (2) State Water Control Board, P. O. Box 11143, Richmond, VA 23230; (3) Lord Fairfax Planning District Commission, 514 North Royal Street, Front Royal, VA 22630; (4) Virginia Division of Forestry, P. O. Box 3758, Charlottesville, VA 22903.

1). The environmental geology map (Plate 2), prepared from the geologic map and from environmental data observed in the field, should be used only as a guide to the distribution of the broad units with similar physical properties. (*A detailed evaluation of an individual site should be conducted by professional personnel.*) Each unit on the map is discussed in sequence as it is related to bedrock age. Thus, unit 1, which is related to the Precambrian Pedlar Formation is discussed first; unit 11, alluvial flood-plain deposits, is last. Major drainage basins have been outlined on the map (Plate 2). East of Rockland the northeastward-trending valley has internal drainage and is properly termed a karst valley (Figure 18). Locations of large sinkholes are plotted on the map (Plate 2) ; cave and rockfall areas are delineated.

The soils information was obtained from the U. S. Soil Conservation Service. Detailed information concerning the soils and specific interpretations for specific uses can be obtained from the local Soil Conservation Service office.

Slopes are defined as follows: low, less than 5 percent; moderate, 5 to 10 percent; and steep, more than 10 percent. The names of the soils used in the descriptions are tentative and subject to change pending a final correlation of the soils of Warren

Figure 18. Karst valley developed on Elbrook Formation east of Rockland.

County. Soil in this report is defined as the lower limit of biological activity (i. e., root penetration) and residuum is considered to be the weathered material between the soil and bedrock. Thicknesses of soils and residuum are based on observations from natural and artificial cuts and on data supplied by the Soil Conservation Service.

UNIT 1

South and east of Dungadin Heights granitic rocks and greenstone dikes are exposed. Slopes are steep along streams and moderate to low in the interstream areas. The frequency of jointing is high and weathering is deep. Outcrops of the granitic rocks are not common. Where roadcuts are 6 to 8 feet deep, weathered rock may be exposed. Generally, the feldspar content of the rocks has been completely altered to clay.

The major soils in this unit are the deep (more than 40 inches or 102 cm), well-drained Fauquier and Myersville soils; both have formed in residuum weathered from the underlying rock. The soil and weathered residuum are 4 to 20 feet (1 to 6 m) thick and free of gravel except near State Road 649.

Good building sites for single and multifamily dwellings and small industrial buildings are available on the low to moderate slopes of the interstream divides except where close to colluvium with danger of landslides. Slippage of soil and weathered residuum is not generally a problem except on the steep slopes along streams and artificial cuts where creep and small slides are common. The area is well suited to farm use except where limited by slope. The moderate permeability may limit many nonfarm uses. Unit 1 appears to be the only area within the Front Royal quadrangle where permeability conditions and thickness of soil and residuum are suited for the construction of a solid-waste disposal facility.

UNIT 2

The area south of State Highway 55 and from Dickey Ridge to the east edge of the map is underlain by greenstone, rhyolitic tuff, and epodisite. Locally, jointing is closely spaced and southeastward-dipping cleavage pervades the rocks.

The dominant soils in this unit have formed in residuum weathered from the underlying rocks; these are the well-drained

Fauquier, Myersville, and Catoctin soils. Cobbles and boulders are locally common on low to moderate slopes and along streams. The Fauquier and Myersville soils are deep—more than 40 inches (102 cm). The depth to bedrock is generally less than 40 inches (102 cm) beneath Catoctin soil.

Where the slopes are low the soil and residuum appear to be stable. Creep, minor slides, and rockfalls may occur on moderate to steep soil. Cuts up to 50 feet (15 m) deep will remain stable and require little maintenance if made perpendicular to the cleavage and bedding and if loose joint blocks are removed during construction. Low slopes have good building sites and in general provide good drainage for septic-tank fields. The Fauquier and Myersville soils are well suited to farming except where limited by slope or stoniness. Catoctin soil is better suited to pasture or woodland. The shallow bedrock and stony soil may make excavation costly in some parts of the area.

UNIT 3

A small area between Dismal Hollow and State Highway 55 and two small hills east of Front Royal are underlain by phyllite, sandstone, and conglomerate. The major soils in this unit formed in residuum weathered from the underlying bedrock. They are well- to excessively drained Hazelton, Dekalb, and Cardiff soils. All the soils contain a high percentage of coarse fragments originating from the underlying bedrock and are droughty. The soil thickness including residuum varies from 2 to 8 feet (1 to 2 m) and is highly acid.

Slopes in this area are moderate to steep; sluffing and minor slides depend on the direction and amount of dip of the beds in relation to the slope of the surface. If the bedding and surface have a steep dip in the same direction, the potential for sliding is greatly increased. If the dip of the slope and bedding are opposite, the potential for rockfalls is increased. Cuts parallel to bedding or cleavage may sluff, forming small rubble piles at the base. Sluffing is greatly reduced if the cut is made perpendicular to the bedding and/or cleavage. The acid soil, moderate to excessive runoff, and steep slopes make this area most suitable for pasture, woodland, and recreational activities; steep slopes and shallow depth to bedrock are severe limiting factors for most nonfarm uses.

UNIT 4

Sandstone and quartzite of the Harpers and Antietam formations and the iron oxide cemented sandstone breccia along the Happy Creek fault tend to have physical properties similar to unit 3. The dominant soils in this unit are the well- to excessively drained Hazelton and Dekalb soils. These droughty, acid soils contain a high percentage of coarse fragments derived from the underlying bedrock. The soils are 2 to 5 feet (1 to 2 m) thick. On moderate slopes the material is stable but on steep slopes slides are common. The sandstone is highly fractured and in deep, nearly vertical cuts there is a potential rockfall danger. Woodland and recreational activities appear to be the best use of this area. Steep slopes and shallow depth to bedrock are severe limiting factors for most uses. Thick colluvium associated with unit 4 is discussed in unit 10.

UNIT 5

This unit extends west of Green Hill and Manassas Run in a northeasterly direction from State Highway 55 to north of the Shenandoah River. The generalized lithology of the rocks of the Waynesboro and lower Elbrook formations underlying the area is argillaceous limestone and dolomite; calcareous shale and siltstone; and clay shale, siltstone, and thin sandstone. Well-drained Frederick and Frankstown soils, developed in residuum from the underlying bedrock, are the dominant soils in this unit. Soil and residuum thickness ranges from 4 to 15 feet (1 to 5 m) with bedrock outcrops covering a significant portion of the area. Over a short horizontal distance of 12 inches (30 cm), the soil-profile thickness may vary as much as 60 inches (152 cm) on the shale, siltstone, and sandstone. A pinnacled-bedrock profile in the limestone and dolomite portion of the area is common. Small sinkholes, less than 10 feet (3 m) in diameter, (not shown on Plate 2) are common. Low and moderate slopes are stable except for minor soil creep. Steep slopes tend to show more creep. High shrink-swell clays are present locally. The presence of sinkholes increases the potential for ground-water pollution and makes the area generally unsuitable for septic systems and sanitary landfills. The area is well suited to farming except where limited by slope or rock outcrops. Moderate permeability and a highly irregular bedrock surface limit nonfarm uses.

UNIT 6

An area underlain by carbonate rocks extends diagonally across the quadrangle from the southwest corner to the northeast corner. Because of the effects of folding and faulting the unit ranges in width from 2000 feet (610 m) southwest of Front Royal to over 2 miles (3 km) northeast of the town. Limestone and dolomite are the dominant rock types; however, thin sandstone beds occur in the base of the Conococheague Formation and chert is locally abundant in the Rockdale Run and Lincolnshire formations. The bedrock-soil-residuum interface is highly irregular (Figure 19)—soil and residuum thickness determinations for construction purposes must be closely spaced because the thickness may vary as much as 40 feet (12 m) over a short horizontal distance due to pinnacle weathering. Well-drained Frederick and Carbo soils, formed in residuum derived from the underlying bedrock, are the dominant soils. The Frederick soils are deeper than 60 inches (152 cm) to bedrock whereas Carbo soils are commonly 20 to 40 inches (51-102 cm) thick. Carbo subsoil horizons are very sticky and plastic. Frederick subsoils are subject to moderate shrink-swell whereas Carbo subsoils are subject to moderate to high shrink-swell (Figure 20). Slope stability de-

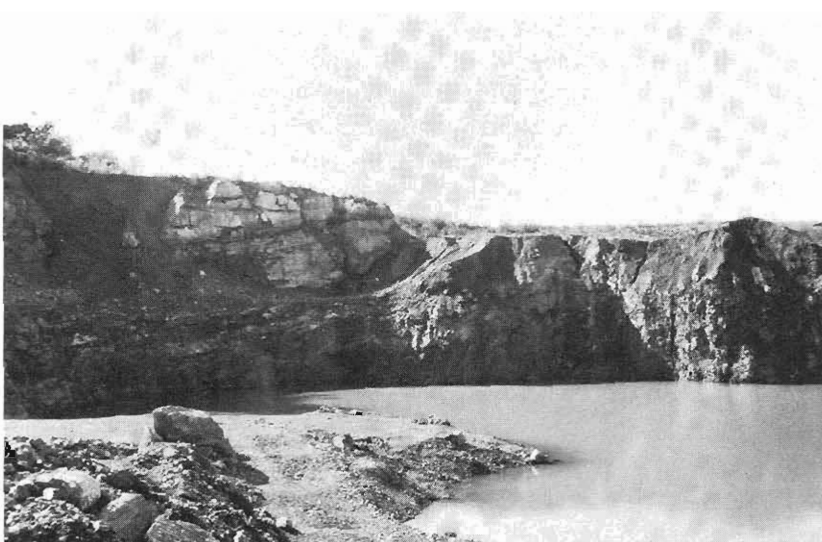

Figure 19. Irregular bedrock-soil interface characteristic of Unit 6; west wall of active quarry number 7.

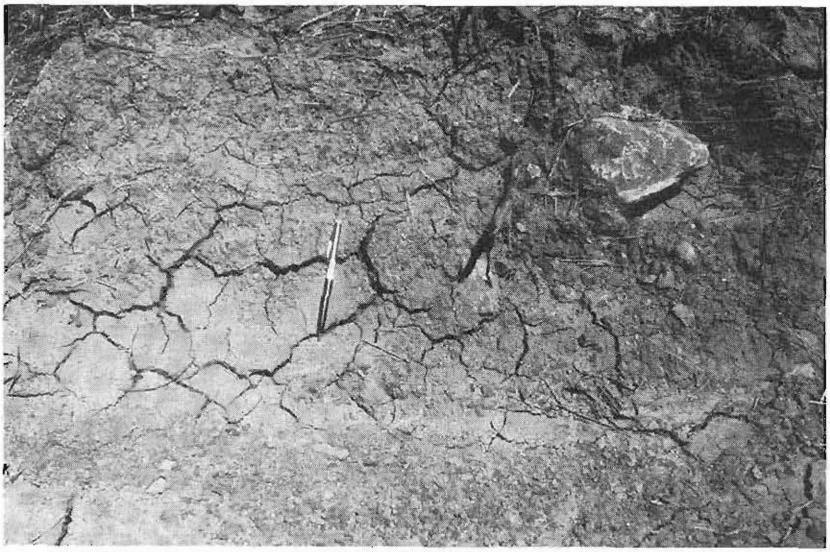

Figure 20. Shrinkage cracks in carbonate residuum along Interstate Highway 66, 1.0 mile (1.6 km) east of Shenandoah River.

pends on the presence or absence of subsurface solution cavities; the spacing, dip, and surface of joints; surface slope; and their relative directions. Rockfalls are common along the steep bluffs of the Shenandoah River where weathering has loosened joint blocks. The abundance of sinkholes poses a potential groundwater pollution hazard. Unit 6 is good for farming except where limited by slope, rock outcrops, or sinkholes. Good building sites are abundant if they are correctly prepared. Care should be used to exclude high shrink-swell soil from the immediate area of any type of construction (i. e., do not use high shrink-swell soil in fill).

UNIT 7

Black shale and limestone of the Edinburg, Oranda, and lower Martinsburg formations form most of the bedrock for unit 7. The unit occurs in a narrow, northeastward-trending belt parallel to U. S. Highway 340/522. Well-drained Carbo, Chilhowie, and Edom soils, formed in residuum derived from the underlying bedrock, are the dominant soils in this unit. The Edom soils are deeper than 40 inches (102 cm) to bedrock. Chilhowie and Carbo soils range from 20 to 40 inches (51 to 102 cm) to bedrock with Carbo soils commonly thicker than Chilhowie. The plastic, sticky subsoil of the Carbo is subject to moderate to high shrink-swell. The plastic, sticky subsoil is thin in Chilhowie soils. A high percentage of shale fragments is common in soils derived from shaly bedrock.

Low to moderate slopes are relatively stable, but runoff may be high if the shale-fragment content of the soil is high. Runoff is high and severe erosion can be expected on steep slopes. If bedding and slope are steep in the same direction, slides are probable (Figure 21). Artificial cuts in this unit require moderate clean-up maintenance. The amount of maintenance may be less if the cuts are perpendicular to bedding strike. Edom soils are well suited to farming except where limited by slope. Carbo and Chilhowie soils are better suited to pasture crops. The presence of shallow soils, some of which are plastic and subject to high shrink-swell, and the presence of sinkholes make waste disposal facilities impractical and increases construction costs for other uses.

UNIT 8

West of the South Fork of the Shenandoah River and Crooked Run, shale and sandstone of the Martinsburg Formation occur.

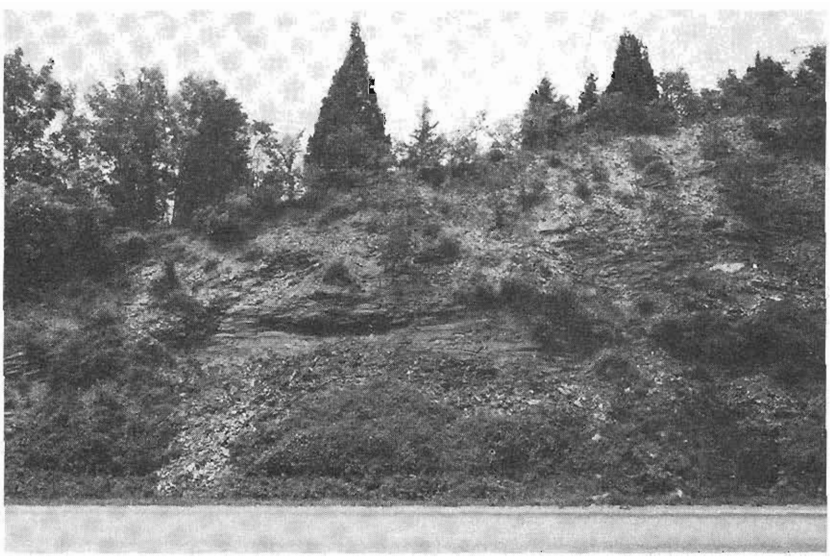

Figure 21. Sluffing of shale in an artificial cut where bedding and slope angles are steep in the same direction; north end of U. S. Highway 340/522 bridge north of Riverton.

Well-drained Berks, Weikert, and Sequoia soils, formed from weathered shale and sandstone residuum, are dominant in this unit. The Berks and Weikert soils have a high content of shale fragments. Weikert soils are shallow, the depth to hard shale being less than 20 inches (51 cm) ; the Berks soils are 20 to 40 inches (51 to 102 cm) thick over shattered shale. Sequoia soils are generally more than 40 inches (102 cm) thick over shale and have a clayey subsoil in contrast to the loamy subsoil of the Berks or Weikert soils. All three soils are droughty. Slopes are steep along streams and moderate to low on interstream divides. Slope stability depends on bedding orientation as related to slope angle and direction. Where the dip of the bedding nearly parallels the slope, slides and sluffing are common. Erosion is a serious hazard on any slopes greater than 10 percent. Artificial cuts exceeding 10 feet (3 m) deep tend to sluff. Agricultural use of the area is better suited to small grain crops and pasture than to row crops. Building sites are generally good but the area has limitations for waste disposal because of the shallow depth to bedrock. The shale and soil of unit 8 could serve as fill to replace high shrink-swell soils of units 5, 6, and 7. Steep slopes in this area limit nonfarm uses. A "perched" water table, locally present in an unnamed soil, has a seasonal wetness limitation.

UNIT 9

Terrace deposits related to the ancestral Shenandoah River are scattered throughout the area. These deposits consist of 0 to 25 feet (0-8 m) of stony, silty clay with a clayey or loamy subsoil. The dominant soils in this unit are in the Unison, Braddock and Monongahela series. Unison and Braddock soils are well drained and have a clayey subsoil. Pebbles and cobbles are common throughout these soils. Monongahela soils are only moderately well drained with a dense, compact loamy layer in the subsoil. This layer inhibits downward movement of water and penetration of plant roots. Seasonal "perched" water is present on this layer. Braddock and Unison soils typically have steeper slopes than Monongahela soils.

On low to moderate slopes of the interstream divides the material is stable but along stream-valley walls the matrix is removed rapidly leaving a deposit of gravel. These gravels may move downslope rapidly if the toe of the slope is disturbed and/or rainfall is moderate. Sluffing and slides are common in deep artificial cuts. Slope is the dominant limitation to farming on Braddock and Unison soils. Seasonal wetness is the major hazard to farming on Monongahela soils. Building sites are generally good. The area has severe limitations for solid and liquid waste disposal facilities because of rapid movement of water through the terrace deposits.

A small terrace deposit occurs along Happy Creek in the town of Front Royal. The deposit is composed of rounded igneous and metamorphic rock pebbles and cobbles in a sandy clay matrix. On low to moderate slopes the material is stable; however, steep slopes tend to sluff and slide, particularly when wet.

UNIT 10

Colluvial deposits present a unique set of environmental characteristics. Fluid percolation rates are high and the thickness ranges from 0 to 25 feet (0 to 8 m). The content of the unit ranges from approximately 10 to 85 percent unconsolidated cobbles and boulders. Two major areas of colluvial deposits are present: west of Dickey Ridge and around Green Hill. The soils west of Dickey Ridge are dominantly Braddock and Unison soils. These soils are deep and well drained. A dense, compact subsoil layer inhibits downward movement of water; lateral water movement is believed to be quite great. Rock fragments, ranging in size from about 1 inch (3 cm) to 6 feet (2 m) in longest dimension, are common. The dominant soils in the Green Hill area are Laidig and Buchanan soils. A dense compact subsoil layer is present. Laidig soils are well drained; Buchanan soils are moderately well drained. Rock fragments, ranging from 1 to 8 inches (3 to 20 cm) in longest dimension, are common.

The area west of Dickey Ridge is well suited to farming except where limited by slope or stoniness. Slope, moderate permeability, and local stoniness are limitations to many nonfarm uses. Steep slope and stoniness limit both farm and nonfarm uses in the Green Hill area. In both areas, if the toe of moderate to steep slopes are cut, earth movements may occur. Under normal rainfall conditions the material may slowly creep downslope. However, during periods of high rainfall the matrix material may be lubricated to such an extent that landslides will occur. These areas are best suited for woodland and recreational activities.

UNIT 11

Low-level flood-plain deposits (alluvium) are extensive along the Shenandoah River, Crooked Run, Cabin Run, Happy Creek, and Manassas Run. The major soils in this unit are soils in the well-drained Genesee and Chagrin series. Included in this unit are areas of unnamed, clayey soils that are poorly drained. The thickness ranges from less than 10 to about 15 feet (3 to 5 m). Only about 5 percent of the deposit is gravel except along Happy Creek and Manassas Run where up to 60 percent of the deposit is composed of granite, greenstone, and quartzite roundstones. Natural slopes range up to 5 percent and are stable. Deep artificial cuts and excavations are subject to slides and sluffing when wet. Flood-plain deposits are prime agricultural areas and a source of topsoil. The poorly drained soils are better suited to pasture crops or trees. Because of periodic flooding the area is not recommended as a building site or for waste disposal.

KARST AREAS

Sinkholes are common in units 5, 6, and 7. In general the larger sinkholes are more numerous in unit 6. Sinkholes less than 20 feet (6 m) in diameter are common in units 5 and 7. Those sinkholes with a diameter exceeding 20 feet (6 m) are plotted on Plate 2. They were located in the field and from interpretation of aerial photographs. Sinkholes provide a primary conduit for recharge of ground water in areas underlain by carbonate rocks and any activity which interferes with this recharge could affect the water table. The potential pollution hazard in areas of karst topography is great due to the underground stream network associated with the sinkholes. Areas of numerous sinkholes indicate subsurface solution activity and collapse of the surface. For this reason the use of the area for buildings requiring high load-bearing strength of bedrock is severely limited.

Caves also indicate considerable subsurface solution activity. For this reason location of buildings requiring high-load capacity would be subject to more severe limitations. Caves and caverns may provide underground storage, a source of economic funds through commercial development, and civil-defense shelters. Areas with one or more cave openings are delineated on Plate 2.

ROCKFALLS

Areas of actual or potential rockfalls are located along the Shenandoah River, Manassas Run, and Happy Creek (Plate 2). Small areas related to abandoned quarry operations and artificial cuts are also shown on Plate 2. Rockfall is defined in this report as the debris which accumulates at the base of steep slopes by relatively free-falling movement. Construction at or near the base of steep slopes where known rockfalls occur is extremely hazardous and subject to severe limitations.

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APPENDIX I

STRATIGRAPHIC SECTIONS

Section 1: Front Royal Country Club

Section begins at dirt road to north of State Road 655, 0.3 mile (0.5 km) southeast of junction of U. S. Highway 340/522 and State Road 655; 0.45 mile (0.72 km) north-northwest of Front Royal Country Club; measured north of golf course toward Potomac Edison powerplant; measured and described by W. E. Nunan.

	Thickness Feet	(Meters)
New Market Limestone		
Limestone, laminated, fine-grained; carbonate pebble conglomerate at base (not measured)		
Rockdale Run Formation (1,167 ft) (356 m)		
Dolomite and limestone with flat pebble conglomerate	80	(24)
Limestone, fine-grained, dove-gray; mottled, laminated; dolomite	75	(23)
Dolomite, mottled, and fine-grained laminated limestone; 70 percent covered	51	(15)
Mostly covered; chert float and 3-foot (1-meter)-thick ledges of laminated dolomite	90	(27)
Dolomite, dolomitic limestone, and limestone	77	(23)
Interbedded dolomite, limestone, and dolomitic limestone; 70 percent covered	98	(30)
Mottled and laminated limestone, dolomite, and dolomitic limestone; flat pebble conglomerate	53	(16)
Dolomite, light-gray, fine-grained, laminated	98	(30)
Dolomite, light- to dark-gray, fine-grained; flat pebble conglomerate	37	(11)
Dolomite, light-gray, laminated; minor dove-gray, mottled limestone	40	(12)
Dolomite, light-gray, fine- to medium-grained	63	(19)
Covered	194	(59)
Dolomite with interbedded mottled limestone	54	(16)
Limestone, fine-grained, mottled, laminated; dolomite, laminated	147	(45)

	Thickness Feet	(Meters)
Fault		
Dolomite, light-gray, fine-grained, laminated	9	(3)

Section 2: Shenandoah River

Begin 0.85 mile (1.36 km) S. 20° E. of junction of U. S. Highway 340/522 and State Road 627 at Cedarville; continue eastward along top of bluffs along Shenandoah River; measured and described by W. E. Nunan.

Rockdale Run Formation (1,384 ft) (422 m)

Dolomite, fine- to medium-grained, light-gray, laminated; blue-weathering, fine-grained, mottled to laminated limestone; medium-grained, mottled dolomite	182	(55)
Interbedded limestone and dolomite, mottled; minor dove-gray, micritic limestone	83	(25)
Limestone, fine-grained, some mottled; gray, medium-grained, mottled dolomite	116	(35)
Limestone, fine-grained, mottled; 60 percent covered	74	(23)
Limestone, mottled, dolomitic; laminated dolomite; limestone, dove-gray, fine-grained	75	(23)
Interbedded limestone and dolomite	49	(15)
Limestone, cleaved, bluish-gray	64	(19)
Dolomite, fine-grained, laminated	34	(10)
Dolomite, laminated, cherty; minor mottled limestone	57	(17)
Dolomite, fine-grained, laminated; minor mottled limestone and chert	98	(30)
Dolomite, laminated; interbedded mottled, dolomitic limestone and fine-grained limestone; 2-inch-chert layer and nodules	277	(85)
Interbedded blue limestone, laminated dolomite, and mottled limestone	45	(13)
Limestone, fine-grained, dove-gray, laminated to mottled	45	(14)
Limestone, algal, fine- to medium-grained, dark-gray, massively bedded; dolomite, medium-grained, gray at 3 (1), 171 (52) and 179 ft (54 m)	185	(55)

Section 3: Rockland

Begins in valley of Willow Brook east of barn and continues to east of State Road 658 (plate 1); measured by W. E. Nunan.

Rockdale Run Formation
Fault

	Thickness Feet	(Meters)
Stonehenge Formation (298 ft) (91 m)		
Limestone, dark-gray, medium-grained, laminated	78	(24)
Limestone, dark- to medium-gray and blue, fine- to medium-grained	72	(22)
Limestone, dark-gray, fine- to medium-grained; laminated dolomite	67	(20)
Limestone, dark-gray, blue weathering, fine-grained; dolomite ribbons; beds of macerated fossil debris	79	(24)
Conococheague Formation (150 ft) (46 m)		
Laminated limestone and dolomite, and a 3-inch (8 cm) thick sandy limestone	150	(46)

APPENDIX II

ROAD LOG

The following road log is a guide to important geologic features that can be seen along or near highways in the Front Royal 7.5-minute quadrangle. Distances between points of interest, as well as cumulative mileage, are shown, and the stops are places where features such as formational contacts, structures, fossils, and interesting rock types or minerals may be observed. *Permission should be obtained from the owner before entering and collecting any samples from private property. Failure to obtain permission to enter violates trespass laws and is punishable under law.*

Cumulative *miles*	*(km)*	*Distance*		*Explanation*
0.0	(0.0)	0.0	(0.0)	Begin road log at intersection of U. S. Highway 522 and State Highway 55, southeast part of Front Royal. Proceed south on U. S. Highway 522.
0.6	(1.0)	0.6	(1.0)	Excellent exposures of the Catoctin Formation on the east (left) side of U. S. Highway 522, showing columnar jointing.
1.3	(2.1)	0.7	(1.1)	*STOP 1.* Roadside pull-off north of (before) the roadcut. This is one of the best exposures of typical Catoctin. Greenstone is the major rock type. Porphyritic greenstone with plagioclase phenocrysts in fine-grained greenstone can be seen in the northern end of the cut and phyllites in the southern end. Epidote, jasper, and asbestos are also common. The red soil formed on the outcrop is typical of the soils weathered from the Catoctin Formation. Turn around, and proceed north on U. S. Highway 522.
2.2	(3.5)	0.9	(1.4)	Turn left (west) onto Criser Road. Note the difference in topography of the Front Royal fault separating Catoctin that was thrust over the Paleozoic carbonates and is crossed just south (left) of this turn. The fault trace is just south (left) of where Criser Road

Cumulative miles	*(km)*	*Distance*		*Explanation*
				crosses Happy Creek. Sheared carbonates of the Conococheague Formation can be seen in the creek north (right) of the bridge. Continue west (ahead) on Criser Road.
3.0	(4.8)	0.8	(1.3)	Junction of Criser Road and U. S. Highway 340. Turn south (left) on U. S. Highway 340.
3.2	(5.1)	0.2	(0.3)	Junction of U. S. Highway 340 and State Road 649 (Browntown Road). Turn southeast (left) on State Road 649.
4.3	(6.9)	1.1	(1.8)	*STOP 2*. Junction of State Roads 649 and 650. Turn right and park on State Road 650. On the east (left) side of State Road 649 (along the abandoned portion) unakite of the Pedlar Formation is exposed on the opposite side of the creek. The contact with the overlying grayish-green metabasalt of the younger Catoctin is sharp. Quartz, epidote, and pink feldspar constitute the unakite. *Panorama:* Note the sharp change in slope from the rugged topography formed by the Catoctin which supports Dickey Ridge to the more gentle topography formed by the Pedlar Formation. The trace of the low-angle Front Royal fault can be seen in the fields to the north, with blocks of the Precambrian Pedlar Formation exposed in close proximity to the carbonates of the Ordovician Rockdale Run Formation. Return to State Road 649, turn right, and continue south (ahead).
5.25	(8.45)	0.95	(1.53)	Junction of State Roads 649 and 607. Turn west (right) on State Road 607.
6.1	(9.8)	0.85	(1.37)	Weathered granodiorite of the Pedlar Formation exposed in roadcut.
6.5	(10.5)	0.4	(0.6)	Pedlar granodiorite exposed in driveway on north (right) side.
6.7	(10.8)	0.2	(0.3)	Greenstone dike in the Pedlar exposed in the creek on the south (left) side of the road.

Cumulative miles	*(km)*	*Distance*		*Explanation*
6.8	(10.9)	0.1	(0.2)	Approximate trace of the Front Royal fault.
6.9	(11.1)	0.1	(0.2)	*STOP 3.* Intersection of State Road 607 and U. S. Highway 340. Park at Rocky Lane Grocery. Carbonates of the Rockdale Run Formation are well exposed behind and south of the store. The trace of the Front Royal fault can be seen fairly well to the east. The hill directly across U. S. Highway 340 from the store is an ironstone breccia, which probably formed by ground-water action on carbonate residuum beneath a gravel deposit *(private property)*. An exposure can be seen along U. S. Highway 340 just south of the store on the opposite side of the highway. Other exposures are scattered on the hillside. In the creek behind Asbury Church just north of the store, thick gravel fill composed mostly of Pedlar materials with some carbonate and sandstone boulders can be seen. This alluvial fill is at least 10 feet (3 m) thick. Return to car and turn north on U. S. Highway 340.
7.3	(11.7)	0.4	(0.6)	Another area of ironstone breccia forms the hill to the east of the highway. There seems to be a higher concentration of iron at this locality. Rockdale Run carbonates crop out along the highway.
7.4	(11.9)	0.1	(0.2)	The long-abandoned Gooney-Manor copper mine (Plate 1, abandoned mine number 15) is located approximately 0.4 mile (0.6 km) down this road. Only ruins of the crusher, the waste dump, and numerous trenches remain. The mine is on *private property*.
9.1	(14.6)	1.7	(2.7)	Abandoned quarry in Ordovician limestone.
9.6	(15.4)	0.5	(0.8)	Skyline Caverns, a commercially developed tourist attraction consisting of a system of solution passages in the Rockdale Run Formation.

Cumulative miles	(km)	Distance		Explanation
9.95	(16.01)	0.35	(0.56)	Intersection of U. S. Highway 340 and State Road 619. Turn west (left) on State Road 619. Note the dip or inclination of the Rockdale Run exposures. The Rockdale Run is faulted onto the Edinburg Formation.
10.20	(16.41)	0.25	(0.40)	Note the flood plain developed on the east side of the Shenandoah River.
10.35	(16.65)	0.15	(0.24)	Roadcut showing vertical black limestone of the Edinburg Formation.
11.0	(17.7)	0.65	(1.05)	Roadcut outcrops of shale and siltstone of the Martinsburg Formation. There are river gravels overlying the bedrock, with the contact irregular due to river channeling during alluvial deposition. Continue west (ahead) on State Road 619.
12.1	(19.5)	1.1	(1.8)	Junction of State Roads 619 and 677. Turn northeast (right) on State Road 677.
13.5	(21.7)	1.4	(2.2)	Note the river gravels and boulders covering Catlett Mountain on the north (left) side of road. These gravels are the highest and oldest terrace deposits in the area. Continue east. The Martinsburg Formation is exposed in several minor roadcuts before reaching the South Fork of the Shenandoah River.
15.0	(24.1)	1.5	(2.4)	Intersection of State Roads 677 and 679. Folding in Edinburg limestone is well exposed adjacent to State Road 677. Continue south on State Road 679. Note the flood plain, levee, and terrace development along the river.
15.6	(25.1)	0.6	(1.0)	Junction of State Roads 679 and 619. Turn east (left).
15.9	(25.6)	0.3	(0.5)	Junction of State Road 619 and U. S. Highway 340. Turn north (left) on U. S. Highway 340. The karst topography developed to the right on the Rockdale Run Formation is very evident when not obscured by foliage.

Cumulative *miles*	*(km)*	*Distance*		*Explanation*
17.05	(27.43)	1.15	(1.85)	Junction U. S. Highway 340 and State Highway 55. Turn east (right) on State Highway 55.
17.9	(28.8)	0.85	(1.37)	Turn north (left) on Jamestown Road.
18.0	(29.0)	0.1	(0.2)	Crushed and broken Antietam sandstone breccia of a fault slice is well exposed in the cut at the top of the hill. Turn around and return to State Highway 55.
18.1	(29.1)	0.1	(0.2)	Intersection of Jamestown Road and State Highway 55. Turn east (left) on State Highway 55.
18.4	(29.6)	0.3	(0.5)	Valley on the north (left) side of highway is underlain by the Waynesboro Formation and the sandstone fault slice borders it on the west. A fault sheet covers the formation approximately 300 feet (91 m) to the south (right) of the highway, bringing the Precambrian Catoctin Formation onto the Cambrian Waynesboro Formation. Continue east on State Highway 55.
19.8	(31.9)	1.4	(2.3)	*STOP 4.* At the bottom of the hill, turn north (left) at entrance of Green Hill Forest subdivision and park. The entire Chilhowee Group is not well exposed in the quadrangle due to structural complications, but exposures in this section include much of what is present. The first unit is the quartz-pebble conglomerate member of the Weverton Formation. This uppermost member consists of light-gray to ferruginous granule- to pebble-sized quartz cemented by silica. The silica has been partially replaced by sericite and limonite. The conglomerate is overlain by a sequence of beds that grade into the lower sandstones and phyllites of the Harpers Formation. This member is exposed on the northern corner of the entrance road and consists of olive-gray and tan silty phyllites and metasandstones. Continue down the unimproved trail to the

Cumulative miles	*(km)*	*Distance*		*Explanation*
				left (*private property*). Note the large amounts of colluvium on the slope to the right. The basal quartzite in the Antietam Formation forms a distinctive ridge about 0.2 mile (0.3 km) from the main highway and is repeated about 0.1 mile (0.2 km) farther down the trail. The quartzite is clean and hard, commonly pressure-welded, with occasional pebble lenses and *Skolithos* tubes. The fault-breccia zone between the Antietam and Waynesboro formations, which has been mapped as a separate unit, is exposed just beyond the second quartzite ridge in the old iron ore mines (Plate 1, abandoned mine numbers 10, 11). The breccia is composed of angular quartzite fragments of varying size cemented with hematite and goethite. Only the open pits of the mining operation and the trail once used as a roadbed for the narrow gauge tramline remain to be seen. Return to the car and turn to the east (left) onto State Highway 55.
22.5	(36.2)	2.7	(4.3)	Junction of State Highway 55 and 647 on adjoining Linden quadrangle. Turn north (left) on State Road 647.
24.5	(39.4)	2.0	(3.2)	Small abandoned quarry in the upper member of the Harpers Formation consisting of light-gray quartzite and subarkosic quartzite with some interbedded phyllite. Good exposures of this member can be seen for the next 0.3 mile (0.5 km) on the right side of the road.
25.4	(40.9)	0.9	(1.5)	Antietam fault breccia of quartzite fragments cemented by iron oxides are exposed adjacent to the road and between this road and Interstate Highway 66 to the east.
25.8	(41.5)	0.4	(0.6)	Junction of State Roads 647 and 624. Turn east (right) on State Road 624.
26.3	(42.3)	0.5	(0.8)	Note the flood plain and two terrace levels along Manassas Run. The road is

Cumulative miles	*(km)*	*Distance*		*Explanation*
				on the lower terrace. The low ridge to the west (left) is held up by red sandstone and dolomite of the Waynesboro Formation whereas the higher ridge to the east (right) is supported by rocks of the Chilhowee Group.
27.6	(44.4)	1.3	(2.1)	Morgan Ford crossing of the Shenandoah River (Linden quadrangle). Continue north on State Road 624.
28.9	(46.5)	1.3	(2.1)	Exposure of middle Elbrook Formation with lithology similar to underlying Waynesboro. Outcrop composed of thin-bedded, fine-grained, pinkish light-gray dolomite and orange decalcified siltstone with a ripply appearance.
29.0	(46.7)	0.1	(0.2)	Intersection of State Roads 624 and 661. Turn west (left) on State Road 661.
29.2	(47.0)	0.2	(0.3)	Large karst valley formed in the Elbrook Formation. It is especially well developed on the north (right) side of the road. The central part of the valley is generally swampy and has an interior drainage system.
30.2	(48.6)	1.0	(1.6)	Intersection of State Roads 661 and 658. *STOP 5.* Cross the intersection and park the vehicle along State Road 661. From the intersection look to the southwest. Rocks at the intersection are in the upper Conococheague Formation whereas the rocks in the foreground between the intersection and Willow Brook are Stonehenge Formation. The rocks exposed on the west side of Willow Brook belong to the Rockdale Run Formation as determined by fossils. The Rockdale Run is in fault contact with the Stonehenge Formation; the fault trace lies approximately in Willow Brook. Continue west on State Road 661.
30.55	(49.15)	0.35	(0.56)	*OPTIONAL STOP 5A.* The Stonehenge Formation is well exposed in the field south (left) of the road (*private property*). The outcrop is predominantly

Cumulative miles	(km)	Distance		Explanation
				fine-grained, dark-gray limestone with crinkly laminations of silt. Thin beds of coarse-grained bioclastic limestone are also common.
30.90	(49.72)	0.35	(0.56)	Norfolk and Western Railway crossing. The Stonehenge-Rockdate Run contact is just west of the railroad.
31.1	(50.0)	0.2	(0.3)	Junction of State Roads 661 and 675. Turn south (left) on State Road 675.
31.9	(51.3)	0.8	(1.3)	The trace of the fault which brings Rockdale Run limestone and dolomite in contact with black Edinburg limestone can be seen on the east side of the low ridge. The Edinburg limestone is on the ridge crest with the Rockdale Run lower on the slope.
32.0	(51.5)	0.1	(0.2)	This is the area where the New Market and Lincolnshire limestones reach their maximum thickness in the study area. The dove-gray micrites of the New Market can be seen in the field to the right of the road. Continue on State Road 675.
32.3	(52.0)	0.3	(0.5)	Junction of State Road 675 and U. S. Highway 340/522. Turn south (left) on U. S. Highway 340/522.
33.8	(54.4)	1.5	(2.4)	Junction of U. S. Highway 340/522 and State Road 658. Turn east (left) on State Road 658 and park at the store. *Obtain permission at house across from store to enter fields. STOP 6.* The Rockdale Run Formation is exposed in a broad anticline for the next 0.25 mile (0.40 km) in the fields north of State Road 658. On the east limb of the anticline, near the small pond about 0.2 mile (0.3 km) north of the road, the unconformity between the Rockdale Run and the overlying New Market is well marked by a conglomerate zone. The Lincolnshire and part of the Edinburg follow in normal sequence to the east, with the fault overriding the Edinburg on the crest of the low ridge.

Cumulative *miles*	*(km)*	*Distance*		*Explanation*
				On the west limb of the anticline, the Rockdale Run extends across U. S. Highway 340/522. The New Market and Lincolnshire formations are very thin and the New Market may be absent. Return to car and U. S. Highway 340/522.
34.25	(55.11)	0.45	(0.72)	*STOP 7.* Park in crossover between lanes of U. S. Highway 340/522. The Lincolnshire-Edinburg contact is very sharp on the east (right) side of the northbound lane of U. S. Highway 340/522. Numerous brachiopods and cephalopods are present in Lincolnshire limestone. Continue south on U. S. Highway 340/522.
34.80	(55.99)	0.55	(0.88)	Junction of U. S. Highway 340/522 and State Road 655. Turn east (left) on State Road 655. Note the anticline and syncline along this road.
35.6	(57.3)	0.8	(1.3)	*STOP 8.* Park just before the Norfolk and Western Railway underpass. Look at structure exposed on the southern side of the hill across the creek. Go south along the railroad tracks (*watch for trains!*) and through the railroad cut. Rockdale Run carbonates are well exposed, having dips of 30° to the southeast. Continue to the end of the cut and notice the marked change in dip. The top of the hill forms a small klippe of Rockdale Run faulted onto Rockdale Run. The quarrying operations of past years have removed much of the original klippe, but the south end remains as a sharp pinnacle about 0.1 mile (0.2 km) to the south. Return to the car and then to junction with U. S. Highway 340/522.
36.4	(58.6)	0.8	(1.3)	Continue south on U. S. Highway 340/522 to the picnic area south of Crooked Run bridge on the east (left) side of the highway and park.
37.4	(60.2)	1.0	(1.6)	*STOP 9. WATCH TRAFFIC!* The gap through Guard Hill is in the lower

Cumulative miles	*(km)*	*Distance*		*Explanation*
				black limey shale of the Martinsburg Formation. The arenaceous sandstone and siltstone increases to the west and can be seen on the dirt road which branches from State Road 637 at the southern end of the gap. The black limestones of the Edinburg Formation with pyrite cubes are well exposed on the abandoned road just south of the rest area. At the south end of the gap, State Road 637 to the east (left) leads to the Riverton Corporation quarries, plants, and office approximately 1 mile (2 km) from the U. S. Highway 340/522 intersection. (*NOTE: Obtain permission from the Riverton Corporation office before investigating on their property.*) The full section of Martinsburg, Oranda(?), Edinburg, Lincolnshire, New Market, and upper Rockdale Run formations is well exposed along the road and in the abandoned quarries. River gravels and boulders are well exposed and show channeling on top of Guard Hill near the old chimney. Return to car and proceed south on U. S. Highway 340/522.
38.1	(61.3)	0.7	(1.1)	Note the terraces and flood plain developed along the south fork of the Shenandoah River.
38.8	(62.4)	0.7	(1.1)	Where U. S. Highway 340/522 turns sharply left continue straight south (ahead) on Shenandoah Avenue in the town of Front Royal.
39.3	(63.2)	0.5	(0.8)	Intersection of Shenandoah Avenue and W. 8th Street. Turn east (left) on W. 8th Street.
39.4	(63.4)	0.1	(0.2)	The Rockdale Run-New Market unconformity is well exposed in back of the Morrison home, 110 W. 8th Street. Continue east on W. 8th Street to intersection with N. Royal Avenue.
39.5	(63.6)	0.1	(0.2)	Turn south (right) on N. Royal Avenue and proceed to traffic light at inter-

Cumulative miles	*(km)*	*Distance*		*Explanation*
				section of N. Royal Avenue and W. 6th Street.
39.65	(63.80)	0.15	(0.24)	Turn east (left) on W. 6th Street.
40.15	(64.60)	0.5	(0.8)	Intersection W. 6th Street and Manassas Avenue. Turn north (left) on Manassas Avenue and continue to railroad crossing at old Front Royal Junction (0.25 mile or 0.40 km). Continue across tracks and on gravel road.
40.60	(65.33)	0.45	(0.72)	*STOP 10.* Park at gates. Ask for permission at the house on the left. Note the wide flood plain formed by Happy Creek. The Rockdale Run is exposed along the creek on the north side beginning from the parking area. The small quarry was used by the railroad to build the bridge across Happy Creek. Around the hill to the southeast the upper Rockdale Run Formation is in fault contact with the Conococheague Formation. The rock lithologies and attitudes are approximately the same, but fossil evidence indicates the faulting. Return to car and retrace route to W. 6th Street.
41.05	(66.05)	0.45	(0.72)	Intersection Manassas Avenue and W. 6th Street. Continue south on Manassas Avenue.
41.30	(66.45)	0.25	(0.40)	Intersection Manassas Avenue and Happy Creek Road. Turn west (right) on Happy Creek Road. Follow main road where it turns to the south.
41.60	(66.94)	0.30	(0.48)	*STOP 11.* Park on south side of Happy Creek. Carbonates of Conococheague Formation are well exposed along the private driveways slightly farther down the street. The outcrop in front of the mansion ("Bel-Aire") is Rockdale Run Formation. The trace of the fault separating these formations has been mapped just west of the road in the flood plain. Gravels derived from the igneous Blue Ridge rocks can be seen

Cumulative miles	*(km)*	*Distance*		*Explanation*
				in Happy Creek. Continue south to junction with U. S. Highway 522 and State Highway 55 Bypass.
41.75	(67.21)	0.15	(0.24)	Turn south (left) on Bypass.
41.90	(67.42)	0.15	(0.24)	Note the Conococheague Formation exposures in the creek and roadcut. The terrace gravels are also very evident at the top of the roadcut.
				End of Log.

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